# NCHRP

## SYNTHESIS 463

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

# Pavement Patching Practices

*A Synthesis of Highway Practice*

TRANSPORTATION RESEARCH BOARD
*OF THE NATIONAL ACADEMIES*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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## *A Synthesis of Highway Practice*

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## NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.



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**Cover figure**: Patching can be used to repair isolated areas of pavement distress, but if the area around the patch continues to deteriorate, as shown here, the first patches obviously did not solve the problem. (*Source*: R. McDaniel).

## FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

## PREFACE

*By Donna L. Vlasak*
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This report summarizes current practices for patching both concrete and asphalt pavements. The intent is to document the state of the practice for patching relatively small-scale surface defects in concrete and asphalt pavements. Both reactive and planned patching is addressed. The synthesis covers management or administrative issues, materials, methods, equipment, specifications and tests, traffic control, and other aspects of patching operations.

The information presented in the report was collected through extensive literature reviews of U.S. and international sources. A total of 49 of 51 survey responses were received from U.S. state highway agencies, a 96.1% response rate. Responses were also obtained from 20 local agencies across the United States, 36 from national, county, and city agencies, and three from maintenance contractors. Five responses were received from Canadian agencies (three provincial and two cities).

The report will be of special interest to state, local, and international highway agencies by assisting them to make informed decisions.

Rebecca S. McDaniel, Jan Olek, and Ali Behnood, Purdue University, West Lafayette, Indiana; Bryan Magee, University of Ulster, Newtownabbey, Northern, Ireland; and Rachel Pollock, Queens's University Belfast, Belfast, Northern, Ireland, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable with the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

## CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

# PAVEMENT PATCHING PRACTICES


## SUMMARY

Pavement patching is one of the most extensive and expensive pavement maintenance activities undertaken by highway agencies at all levels. Because of the costs and resources involved in this massive undertaking, there are significant benefits to be attained by managing patching programs in the most cost-effective manner.

This synthesis summarizes current practices for patching both concrete and asphalt pavements. The intent is to document the state of the practice for patching relatively small-scale surface defects in concrete and asphalt pavements. Larger scale patching, wedge and level (or level-up patching), and pre-overlay patching are not addressed. Both reactive and planned patching are addressed. The synthesis covers management or administrative issues, materials, methods, equipment, specifications and tests, traffic control, and other aspects of patching operations.

The Strategic Highway Research Program (SHRP) had three contracts dealing, in part, with pavement patching. These efforts led to evaluations of various materials for patching asphalt and concrete pavements, standardized terms for different patch installation procedures, and a prototype automated patching vehicle. This synthesis compares current practices with those recommended through these SHRP projects to see what changes have been made since the close of the SHRP program.

The information contained herein was collected through extensive literature reviews of U.S. and international sources, summarized in chapter two; and electronic surveys and follow-up phone and e-mail interviews, summarized in chapter three. A total of 49 survey responses were received from U.S. state highway agencies, a 96.1% response rate. Responses were also obtained from 20 local agencies across the United States. In addition, a similar survey was distributed in the United Kingdom and Ireland, where 36 responses were received from national, county, and city agencies, as well as three maintenance contractors. Five responses were received from Canadian agencies (three provincial and two cities). The U.S. local and international responses are presented in chapter four. Four case examples are offered in chapter five to demonstrate common practices and innovations. The conclusions from the synthesis, gaps identified in the existing knowledge, and areas for future research, as identified through the surveys, are summarized in chapter six.

Almost all U.S. states place great importance on pavement patching. Only a few states (five of 49), predominantly in areas of the country where freezing temperatures are uncommon, indicated that they did not consider patching to be a major component of their maintenance programs.

There are similarities and differences in patching practices across the states. The distresses addressed by patching and the triggers that call for patching are similar, both for the states and local agencies in the United States and internationally. Engineering judgment is extensively relied upon to determine when and where to patch, the type of patch to install, and when patching is not an appropriate repair to make. Many agencies have guidelines to promote consistency across district or regional lines and to improve pavement service levels overall.

The materials used for patching vary widely, but fall into several general categories. Asphalt materials are most commonly used for temporary patching of both concrete and asphalt pavements. Permanent patches on concrete pavements are commonly made with cementitious materials of varying types, depending on the type of patch, type of roadway, and how long the patch can be allowed to cure or set. Epoxies and other polymeric materials are sometimes but less commonly used, largely because of the costs and complexity in handling and placement. On asphalt pavements, hot mix asphalt remains the preferred material for semi-permanent patching; however, the use of spray injection patching is increasing and the performance is reportedly approaching semi-permanent status in some states. This success, however, has not been found in all states.

Transportation agency employees do most of the patching in states and local agencies, especially for reactive patching. Some states are making increasing use of maintenance contracts; however, these are still not common. Maintenance contracts are much more common overseas.

Traffic control measures vary considerably depending on factors such as the duration of the patching process, type of roadway, and traffic volumes. No major differences were noted between the types and locations of agencies and the traffic control measures implemented.

SHRP research led to the development of manuals for patching potholes and partial depth repair of spalls on concrete pavements. For the most part, the recommendations in those manuals have been widely implemented. The patching materials evaluated in the SHRP studies are mostly still on the market, although there have been some formulation and name changes. SHRP-recommended tests for patching materials have been implemented to some extent; however, some recommended tests for workability and cohesion are not commonly used.

The automated patching vehicle developed under SHRP never progressed beyond the prototype stage and reportedly did not perform as designed. Although the device itself was not implemented as designed, the concept of using spray injection patching has been widely implemented and is basically the same as that part of the SHRP prototype. The use of spray injection patching, which performed well in the SHRP research, has increased dramatically and is quite common in many states.

On concrete pavements, partial depth patching, which performed well in the SHRP research, has also been widely implemented. The use of proprietary patching materials or higher quality generic patching materials has also increased.

The 110 agencies and organizations responding to the survey reported various needs for additional research, especially with regard to new or innovative materials, new procedures, cost-effectiveness, and comparison of different patching materials. There were a number of similarities in the needs expressed through the survey by the responding state, local, and international agencies.

CHAPTER ONE

# INTRODUCTION

This chapter introduces the synthesis topic and need for information on current pavement patching practices. It defines the scope of the project and the approach used to gather pertinent information. It also defines terms used in the synthesis to describe pavement distresses, patching types, such as reactive versus planned repairs, and patching techniques. Lastly, the results of the Strategic Highway Research Program (SHRP) studies on pavement patching are reviewed for comparison with current practices.

## BACKGROUND

Despite advances in material selection and pavement design, pavement distresses and failures still occur. When they do so on a small scale or in fairly isolated locations patching is the most common maintenance technique used to restore pavement functionality.

While actual figures are difficult to obtain, it is safe to assume that well over $1 billion is spent each year to maintain roadways in the United States. In 1999, it was estimated that more than $1 billion was spent annually in the United States on pothole and spall repair (*1*) and costs have increased since then. With such a large expenditure of tax dollars, it is important to ensure that the funds are spent in a cost-effective manner and that the investments in patching result in improved pavement performance and longer service lives.

## SYNTHESIS SCOPE

This synthesis documents the current state of the practice regarding pavement patching practices and updates the information available on patching practices to enable agencies to make informed decisions about their own patching policies and procedures. It is intended to document the state of the practice for patching relatively small-scale defects or distresses in both asphalt and concrete pavements. Large-scale patches, wedge and level (or level-up patching), and pre-overlay patching are not the focus. In particular, the synthesis examines the following:

- Current programs for repair and patching;
- Pavement distress factors that identify a good candidate for repair and patching;
- Performance information under different conditions such as season, time available, and traffic;
- Repair and patching materials and associated performance for both asphalt and concrete pavements;
- Review of public and private repair and patching specifications, including quality measurement practices such as smoothness and density control for asphalt patching and opening strength for concrete patches;
- Repair and patching design and construction practices for manual and automated repairs;
- Traffic control requirements and practices for pavement repair and patching;
- Repair and patching equipment, including types of automated equipment;
- Methodology to track and report on patches, such as Global Positioning System (GPS) and geographic information system (GIS) mapping tools and maintenance management condition assessment systems or processes;
- Unit cost information; and
- Ongoing research and future needs.

The main focus of this synthesis is on reactive, manually installed patches over relatively small areas; however, some information was also gathered on planned and machine-fabricated patches. The focus is also on patching that is intended to serve traffic for some time, whether temporarily or permanently, and does not include patches placed immediately before placement of an overlay.

## SYNTHESIS APPROACH AND REPORT ORGANIZATION

The information presented in this synthesis was collected in several ways. First, a comprehensive literature search was performed using the TRID database, Google, Elsevier, and Compendex. Pertinent citations were also suggested by survey respondents and others. The citations were reviewed and categorized as to their primary topics (e.g., patching asphalt or concrete pavements, equipment, management, specifications, and health and safety). The literature review primarily, but not exclusively, focused on publications released since the SHRP research, because the SHRP researchers had conducted extensive reviews of literature published prior to the SHRP program. More than 100 references were reviewed in preparing this synthesis, and the information from this literature review is provided in chapter two.

A second approach was a survey of U.S. state agencies, which was used to collect electronic responses to a screening survey to identify states with the most information on particular aspects of patching practices. A total of 48 states plus the District of Columbia responded to the survey; a response rate of 96.1%. A copy of the survey, list of agencies responding to the survey, and tabulations of survey responses are provided in Appendices A–C.

Following the screening survey, to elicit additional information, selected states were interviewed by phone or questioned by e-mail. A core set of follow-up questions was developed and used during the phone interviews to guide the discussion; however, the interviews were loosely structured to allow latitude to gather as much information as possible. Summaries of the findings of the U.S. survey and follow-up interviews are provided in chapter three.

A similar survey was distributed to a number of local U.S. transportation agencies. A request for information was sent to the Local Technical Assistance Program (LTAP) offices in 16 states representing different climatic regions. The LTAP centers were asked to forward the request to the appropriate agencies within their states. In one case, the LTAP center felt informed enough to provide answers for the local agencies in the state as a whole. A total of 20 responses representing local agencies in eight states were received. These responses are summarized and compared with the responses from state agencies in chapter four.

A third electronic survey was developed and sent to agencies in the United Kingdom and Ireland, including national agencies, local (city or county council) agencies, and some private contractors. A total of 36 responses were received. Lastly, responses were received from five Canadian agencies; three provincial and two from large cities. Information from this survey is presented and comparisons with U.S. practices are made in chapter four.

Chapter five includes four case examples of selected agencies and their innovative or informative practices. Chapter six summarizes the collective findings of the synthesis effort and identifies gaps in the knowledge and future research needs as identified by the survey respondents.

## BASIC CONCEPTS AND DEFINITIONS

This synthesis is focused on patching practices for both asphalt and concrete pavements. Many of the terms used frequently throughout this report are defined here for clarity. As a general note, the District of Columbia is, for purposes of this summary, grouped with the state agencies. When the term "state" is used, it is intended to include the District of Columbia.

### Distresses Suitable for Repair by Patching

For the most part, the definitions of the distress terms used herein correspond to those in the *Distress Identification Manual for the Long-Term Performance Program*, commonly referred to as the *DIM* (*2*). Many states use this manual and therefore are familiar with the terminology.

In asphalt pavements, the most common distresses that can be repaired by patching include potholes, deterioration around cracks, delaminations, rutting, or raveling. The *DIM* does not include deterioration around a crack as a distress, but does include high severity cracking, which could describe this type of deterioration. In this document, the term "delamination" refers to the separation of one layer of an asphalt pavement from the underlying layer; some refer to this as "peeling." In the *DIM*, this would be categorized as a pothole. One distinguishing feature of a delamination versus a pothole is that a delamination has a flat bottom at the top of the underlying layer, whereas a pothole is bowl-shaped. Figures 1 and 2 illustrate potholes and delaminations, respectively.

Technically speaking, concrete pavements do not experience potholes. The term pothole, however, is sometimes used in the literature as a generic term for a hole requiring patching. In this document, the area to be patched is sometimes referred to as a "hole" for brevity, although the area to be patched may exhibit some distress other than a pothole.

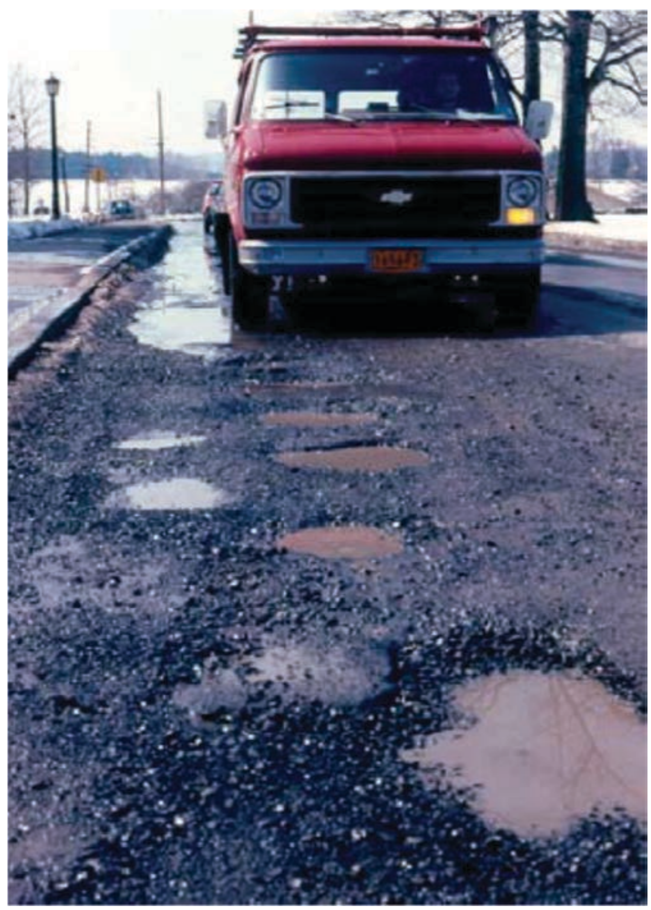


FIGURE 1 Potholes caused by poor drainage (*Source*: Cornell Local Roads Program, CLRP).

FIGURE 2 Delamination of surface layer (*Source*: CLRP).

In concrete pavements, some of the distresses that can be addressed through patching include deterioration around cracks (such as durability "D" cracks, map cracking, and longitudinal or transverse cracks), scaling, popouts, and blow-ups. In addition, jointed concrete pavements may experience joint spalling (Figure 3), corner breaks (Figure 4), faulting, and damage caused by water pumping that can be repaired by patching. Continuously reinforced concrete may be subject to punch-outs as well. As with asphalt pavements, the *DIM* does not consider deterioration around cracks as a distress type on concrete pavement; however, deterioration around a crack could be considered analogous to spalling at a joint.

Patching is also used to repair deteriorated patches or around previous patches on both pavement surfaces (Figures 5 and 6). If the area around a patch continues to deteriorate, the first patch did not solve the problem.

FIGURE 3 Patched concrete joint spalls (*Source*: R. McDaniel).

FIGURE 4 Patched corner break in concrete pavement (*Source*: R. McDaniel).

### Types of Patches

Some of these distresses can happen suddenly, requiring reactive or emergency repairs, while others progress more gradually, allowing an agency time to plan, and perhaps contract out, the repair. In this document, these are referred to as reactive and planned patches, respectively. Reactive patching is sometimes called demand patching in the literature.

Depending on factors such as the time of year, availability of repair materials, or traffic conditions, temporary patches are often placed to hold the pavement over until more permanent patches can be placed. Temporary patches are often placed in the winter or during other adverse conditions to address an immediate safety or ride quality problem. The term semi-permanent is sometimes used in the literature to refer to longer lasting repairs on asphalt pavements, while long-lasting patches on concrete pavements are often considered permanent.

FIGURE 5 Multiple asphalt patches on concrete pavement (*Source*: R. McDaniel).

FIGURE 6 Multiple patches on asphalt pavement (*Source*: R. McDaniel).

## Patch Materials

A wide variety of materials is used for patching, especially for concrete pavements. Some form of asphalt mixture is commonly used to patch both asphalt and concrete pavements. Asphalt patches on concrete pavements are frequently considered temporary patches. Concrete pavements may also be patched using cementitious materials of various types, which are generally considered to be more permanent repairs. Polymeric materials have been used on both types of pavement as well. Injection patching, by blowing asphalt emulsion and aggregate into the area to be patched, is sometimes used, especially in winter when hot mix materials are not available.

As used herein, hot mix asphalt is a typical asphalt mixture produced through a hot mix plant. Few states reported using warm mix asphalt, but if they do that mix would be similar to a hot mix. Cold mix, cold emulsion mix, or generic stockpile mix are terms used to refer to asphalt mixtures that can be stockpiled and worked when cold; they are often produced through a hot mix plant, then allowed to cool in a stockpile for later use. Proprietary cold mix is similar but utilizes some proprietary formulation, often of the asphalt binder; these are designated by their trade names. Proprietary patching materials are sometimes sold in bags rather than being stockpiled.

Materials used for patching concrete pavements, aside from asphalt patching materials, include mixtures with cementitious materials such as normal hydraulic cement, rapid strength hydraulic cement, calcium aluminate, calcium sulfoaluminate, magnesium phosphate, and other cementing agents. At times latex or polymer-modified concretes are also used. Epoxy materials are less common, but also available.

## Patch Preparation and Placement Methods

There are a number of different methods of preparing the area to be patched and placing the patching materials. These were standardized to some extent during the SHRP research that is discussed in the following section. As defined by SHRP and used in this document the methods are described as follows.

For placing asphalt patching material, either on an asphalt or a concrete surface, the descriptive term throw-and-go refers to simply filling the hole with patching material and moving on to the next hole. Somewhat more effort is expended in the throw-and-roll technique, where truck tires are used to compact the patching material after placement (Figure 7). Both the throw-and-go and throw-and-roll methods can be used for temporary patching under adverse conditions, such as in winter or for a sudden problem under heavy traffic, although the throw-and-go technique is generally not recommended.

A semi-permanent patch involves considerably more preparation and compaction and therefore is usually not feasible under adverse conditions (Figure 8). In this method, used for asphalt surfaces, water and debris are removed from the area by an air compressor or broom (mechanical or manual). The sides of the area to be patched are cut back to sound material and made vertical by hand or power equipment (such as saws,

FIGURE 7 Rolling a patch with truck tires (*Source*: CLRP).

FIGURE 8 A semi-permanent patch on asphalt pavement (*Source*: R. McDaniel).

FIGURE 10 Edge seal misapplied on throw-and-roll patch (*Source*: R. McDaniel).

picks and shovels, or milling machines). The patching mix is placed in the prepared hole and is compacted using a vibrating plate, vibratory roller, or other equipment (*3*).

The edge seal method is similar to the throw-and-roll or semi-permanent technique except that a crew returns after the patch has set and seals the edges of the patch. This is usually used on asphalt surfaces only (see Figures 9 and 10). During the SHRP research, one similar agency-requested technique evaluated was used in Illinois and involved sealing the entire surface of the patch, rather than just the edge, and dusting it with sand (*4*).

In all of these cases, the SHRP *Manual of Practice* calls for checking that the patch has a slight crown to help drain away water and to allow for some densification under traffic (*4*).

The spray injection method uses specialized trailer- or truck-mounted equipment to blow water and debris from the pothole, spray a tack coat into the hole, blow asphalt and aggregate together into the hole, then cover the patch with a layer of aggregate (see Figure 11). Because the aggregate and emulsion are propelled into the patch area with high pressure air no further compaction is necessary. Spray patching can be used on asphalt or concrete pavements and is sometimes done under adverse conditions because of the speed with which it can be accomplished (*5*).

Many types of distress on concrete pavements can be repaired using partial or shallow depth patching if the distress is confined to the top third to half of the slab; the unsound material is removed and a patch installed. (Deeper distresses require full-depth repairs.) Techniques for permanent patching

FIGURE 9 Excellent edge seal on semi-permanent asphalt patch (*Source*: R. McDaniel).

FIGURE 11 Patching with trailer-mounted spray injection patcher (*Source*: Ohio DOT).

FIGURE 12 A sawed patch on concrete pavement with reinstated tining (*Source*: R. McDaniel).

of concrete pavements as used in the SHRP research on partial depth spall repair include the following (*6*):

- Saw and patch—where straight vertical faces are produced by sawing.
- Chip and patch—where loose or unsound material is removed by pneumatic hammer or other tools and concrete faces at least 1 in. deep are formed around the patch.
- Mill and patch—where a milling machine is used to remove unsound material to a depth of at least 1.5 in. and vertical edges are formed in corners with chipping hammers.
- Waterblast and patch—where unsound concrete is removed to a depth of at least 1.5 in. and vertical faces are formed by waterblasting.
- Clean and patch—where unsound concrete is removed with hand tools; during the SHRP research, this was used only with the spray injection method.

Figure 12 shows an example of a sawed and patched repair where the concrete tining has been reinstated over the patched area.

These techniques are still used today. Milling and waterblasting to prepare the areas to patch are generally less common than the other techniques because of the equipment required.

## STRATEGIC HIGHWAY RESEARCH PROGRAM RESEARCH ON PATCHING

As mentioned in the Introduction (chapter one), one goal of this synthesis is to compare today's practices with the recommendations made in the SHRP research on pothole and spall repair. To do that, the SHRP findings must be recognized and discussed. This section briefly outlines some of the main findings of the SHRP research on patching.

Beginning in the late 1980s and ending in 1993, SHRP was directed to develop high-payoff products in six focused areas of national need. One of these areas was highway maintenance. As a part of that effort, three SHRP contracts, H-105, H-106, and H-107, addressed materials, procedures, and equipment for some routine maintenance activities. Under H-105, Innovative Materials and Equipment for Pavement Surface Repair, an extensive literature review was undertaken and highway agencies across the country were surveyed to identify promising options for the repair or treatment of potholes, cracks, joints, and spalls. (This review will focus on the findings regarding pothole repair in asphalt-surfaced roadways and spall repair on concrete surfaces; joint and crack repair are beyond the scope of this synthesis.) Based on the results of H-105, H-106 evaluated the construction and performance of field test sections with various materials, patching procedures, climates, traffic levels, and other factors. These test sections were monitored for approximately 18 months after installation, until the end of the SHRP program. At the close of the SHRP program, the Long-Term Pavement Performance (LTPP) team at FHWA agreed to let a contract to continue monitoring the test sites for an additional 48 months. The final reports and manuals were published by FHWA in 1999. The third contract, H-107, resulted in the development of automated equipment for pothole patching, as well as joint and crack sealing.

### SHRP Research on Pothole Repair

Research conducted under contracts H-105 and H-106 led to several reports including Evans et al. (*3*) and Smith et al. (*7*), and a *Manual of Practice for Materials and Procedures for the Repair of Potholes in Asphalt-Surfaced Pavements* (*4*). As mentioned previously, the manual was updated by FHWA in 1999 (*5*).

The field studies under contract H-106 involved the placement and performance monitoring of 1,250 pothole patches at 22 sites in four climatic regions on two pavement types (flexible and composite). The patches evaluated used cold mix stockpile materials and spray injection; hot mix was not included because the focus was on materials that could be placed in any weather. A proprietary product named UPM, placed with the throw-and-roll technique defined earlier in this chapter, was considered the control and was used at all the test sites. The materials and repair procedures used are shown in Table 1.

UPM, Perma-Patch, and QPR 2000 are proprietary patching materials. As noted previously, UPM was considered the control material for these field evaluations. The HFMS mixture used a high float medium setting emulsion to produce a non-proprietary cold mix suitable for stockpiling until needed. The Pennsylvania DOT (PennDOT) mixes were also suitable for stockpiling. They used a gradation similar to the UPM with clean, angular aggregates, but had different binders and were not proprietary; PennDOT 486 included fibers to aid in

TABLE 1
MATERIALS AND PROCEDURES USED IN
H-106 FIELD EVALUATIONS

| Material | Repair Procedure |
|---|---|
| UPM High Performance Cold Mix (control) | Throw-and-roll |
| | Edge seal |
| | Semi-permanent |
| PennDOT 485 | Throw-and-roll |
| | Edge seal |
| | Semi-permanent |
| PennDOT 486 (polyester fibers) | Throw-and-roll |
| Local Materials | Throw-and-roll |
| | Surface seal |
| | Heated with propane torch |
| HFMS-2 with Styrelf | Throw-and-roll |
| Perma-Patch | Throw-and-roll |
| QPR 2000 | Throw-and-roll |
| | Semi-permanent |
| Spray Injection | Spray injection |
| Agency Request | Agency request |

*Source*: Mojab et al. (*6*).

stability and prevent draindown of the binder. Spray injection patching was defined in "Patch Preparation and Placement Methods." The "Local Materials" were generic, "every day" cold mixes (*8*) common to each state, and "Agency Request" signified a technique or material the agency wanted to evaluate. One example was Illinois' previously mentioned use of sealing over the entire patch area and spreading with sand.

Among the repair procedures the throw-and-roll placement technique is widely used, especially under adverse weather conditions, because it has a high productivity rate and repairs can be effected quickly. The technique is considered superior to the throw-and-go technique because the effort to compact the material into the pothole generally leads to a longer lasting patch that is less likely to be affected by traffic than loose material (*4*). The spray injection method involves higher costs for the equipment, but the higher productivity rate and reportedly lower material costs make it attractive. Because of the speed at which patching can be performed, there is less worker exposure to traffic as well, making the operation safer.

The findings from the field evaluations generally showed that (*3, 8, 9*):

- The performance of patches placed with the throw-and-roll technique was comparable to the semi-permanent patches in head-to-head comparisons with three different materials. In addition, the throw-and-roll technique was more cost-effective (higher productivity and lower costs). Since the performance was comparable, the lower costs made throw-and-roll more cost-effective on a life-cycle basis.
- The success of the throw-and-roll technique depended on the use of high-quality materials, such as proprietary cold mixes.
- Spray injection was a "viable" option and performed as well as the control patches at all locations (*8*). However, the method was found to be more heavily dependent on the skills of the operator than the other methods and to require use of angular aggregates and a compatible asphalt emulsion. It was noted that the absorption of the aggregate needed to be taken into account to ensure there is enough binder added.
- The methods best suited to use in winter conditions were the throw-and-roll or spray injection methods because of the speed with which patches could be installed.
- Patches placed in the wet-freeze climatic area did not perform as well as those placed in the dry-freeze region. Similarly, patches placed under adverse weather conditions did not perform as well as those placed during warmer, drier periods.
- The first few weeks after the patch was placed were deemed the most critical as the material was still setting during this time.
- With good materials and proper techniques patches could perform for several years.

The *Manual of Practice* (*4*, *5*) covers the use of cold mix stockpile materials using the throw-and-roll or semi-permanent techniques and the use of the spray injection method. The steps are as outlined in "Patch Preparation and Placement Methods." The manual also addresses safety issues, including traffic control, following manufacturers' guidelines, referring to the Material Safety Data Sheets (MSDSs) for proprietary materials, and wearing eye protection when using the spray injection method. The manual recommends use of the throw-and-roll technique in winter conditions with patching mix made with high-quality aggregate, few fines, and an emulsion with an anti-strip additive. In spring conditions either the throw-and-roll, spray injection, or semi-permanent installation methods are recommended. The materials used in the spring may be the same as in the winter, although they reportedly may be sticky and harder to work with at warmer temperatures.

The manual also suggests testing the compatibility of the asphalt binder and aggregate, at least if the combination has not been used before. This testing would require checking:

1. Coating—at least 90% retention;
2. Stripping—at least 90% coating retention; and
3. Drainage—loss of no more than 4% of the weight of residual binder. (This is now more typically called draindown from experience with open-graded asphalt and stone mastic asphalt mix design.) The specific test methods are described in the manuals (*4, 5*).

For acceptance of patching material, the manual also recommends testing the workability with a workability box and modified pocket penetrometer. Another acceptance test evaluates the cohesion of the patching material. Again, the test methods are described in the manuals (*4, 5*).

A method to determine the patch survival rate based on the number of patches remaining in place over time is also presented. A worksheet to estimate patching costs is provided in the manuals (*4, 5*).

The productivity of the various pothole patching operations was evaluated at each test site. Table 2 summarizes the times to place different types of patches (*9*). Again, throw-and-roll and spray injection were comparable in terms of tons per hour placed and time per patch. It is important to note, however, that the productivity reported here includes the time for patching only and does not include such factors as mobilization.

Evaluation of the test sections placed under H-106 was continued under the LTPP Program. A 1999 Tech Brief on the subject (*10*) concluded that:

- The throw-and-roll technique was more cost-effective in most cases than the semi-permanent procedure, if quality patching mixtures were used.
- After roughly three to four plus years, 56% of the patches placed had survived, 31% had failed, and 13% had been overlaid.
- The spray injection technique continued to demonstrate good performance with a skilled operator.
- Three of the eight agencies that placed test sections had converted from using their local patching mixtures to one of the tested materials and one agency had purchased a spray patcher based on the good performance and cost-effectiveness observed during the study.

In addition, this longer review under LTPP confirmed the recommendations offered in the SHRP reports regarding using throw-and-roll or spray patching practices in adverse weather conditions, using high-quality materials, considering safety and user delay when selecting the patching technique, and testing compatibility of the asphalt and aggregate (*10*).

### SHRP Research on Spall Repair

Spalls on a concrete surface are typically repaired with shallow depth patching. Research under SHRP contracts H-105 and H-106 evaluated the performance of various materials and repair procedures used in different climates and under differing atmospheric conditions at the time of placement. In the course of the SHRP research, 1,600 spalls were repaired and monitored for approximately 18 months. Partial-depth patches might be expected to last for five to ten years; therefore, the findings in the SHRP report were considered preliminary (*6*). These spall repairs were monitored by FHWA/LTPP for an additional four years and a final report, manual, and Tech Brief were published in 1999 (*11–13*).

The products evaluated in the field included Type III Portland Cement, Duracal®, Set-45®, Five Star® HP, MC-64, SikaPronto® II, Percol FL, UPM High Performance Cold Mix, Pyrament® 505, Penetron® R/M-3003, and spray injection cold mix (using two different devices, AMZ and Rosco) (*6*). Six different preparation techniques were used, including the saw and patch, chip and patch, mill and patch, waterblast and patch, and clean and patch methods defined in "Patch Preparation and Placement Methods." In addition, minimal preparation under adverse conditions was also done as a worst-case scenario. In this case, only hand tools were used to remove unsound concrete and water was sprayed into the hole, if not already present. If dowel bars were exposed or the depth of removed material was greater than half the nominal pavement thickness, a full-depth patch was recommended instead of a partial-depth patch.

The findings included the following (*6*):

- Partial-depth patches performed well over the course of the study.
- There were significant performance differences between some of the cementitious and polymer materials in terms of many performance measures in some or all climates.
- There were also some differences in various aspects of the performance of asphalt materials in the wet-freeze and wet-nonfreeze regions.

TABLE 2
PRODUCTIVITY OF PATCHING USING DIFFERENT METHODS

| Method | Range (min/patch) | Average (min/patch) | Ave. Productivity (tons/hr) |
|---|---|---|---|
| Throw-and-Roll | 1.5–5.0 | 2.6 | 1.6 |
| Edge Seal | 2.5–5.4 | 3.2 | 1.4 |
| Semi-Permanent | 4.2–27.0 | 13.3 | 0.3 |
| Spray Injection | 1.9–4.6 | 2.8 | 1.7 |

*Source*: Wilson and Romine (*4*).

- Installation temperature had minimal effect on performance except for the longitudinal cracking of polymer and cementitious patching materials in the dry-freeze region.
- Type III cement performed comparably to proprietary cementitious patching materials.
- Only three combinations of preparation method, patching material, and climate exhibited poor performance compared with the other combinations; these were Percol FL with saw-and-patch in the dry-nonfreeze region, Set-45 with chip and patch in the wet-freeze region, and Percol FL with chip and patch in the wet-nonfreeze region.
- Differences were observed between the spall preparation techniques but, as noted previously, these differed by climate and patching material used. There were no clear trends in the performance and, since almost all of the patches were performing well, rankings of the different factors was not possible.

The final report published by FHWA (*11*) confirmed that most of the partial depth repairs and the Type III cement performed well. The repairs made with the chip and patch technique performed as well as or better than those with the saw and patch method and were less expensive, resulting in lower annual costs. The waterblast and patch method was effective when done by an experienced operator with properly working equipment.

### SHRP Development of Automated Pothole Patching Machine

Under SHRP contract H-107B, a prototype completely automated pothole patching machine, called the Automated Pavement Repair Vehicle (APRV), was developed (*14*). The machine was intended to reduce the cost of patching by reducing the labor requirements to one or two operators; to improve safety by allowing the operator(s) to work from the cab of the vehicle; to speed the repair process, which would improve safety and reduce delays for motorists; and to allow repairs to be installed in varying weather conditions or at night with a variety of materials. Potholes were identified and repaired using a computer vision system and robot. The device was designed to cut around the area to be patched (if desired), clean the hole, heat and dry the interior of the hole, and spray in the patching aggregate and binder. Basically, the patch would be formed using the spray injection method; however, the remainder of the process, specifically preparing to patch, was reportedly improved and automated (*14*).

It was estimated that automated repairs using the APRV could save, on average, about $55 per pothole filled. In addition, it was maintained that the system would be safer, result in fewer traffic delays, and lower vehicle maintenance costs because of the improved road conditions.

### Summary

As with other areas of the program, the SHRP research on pothole patching and spall repair was unprecedented in scope and scale. The results led to increased standardization of terminology; improved materials, tests, and techniques available for implementation; and development of some innovative technologies. In later chapters, this synthesis will explore and summarize which of the SHRP recommendations have been implemented.

CHAPTER TWO

# LITERATURE REVIEW ON PAVEMENT PATCHING PRACTICES

This chapter summarizes the findings of the literature review regarding pavement patching practices for asphalt and concrete pavement surfaces. The literature review is presented in three parts: (1) patching as part of a maintenance program, (2) patching asphalt pavements, and (3) patching concrete pavements. There is often considerable overlap in the topic areas covered in individual reports and papers; therefore, these are not absolutely clear-cut distinctions.

## PAVEMENT PATCHING AS PART OF MAINTENANCE PROGRAMS

This section summarizes general, more administrative information about pavement patching by agencies gleaned from the literature review. Although pavement patching may appear to some to be a simple, routine maintenance activity, the costs associated with patching can be very high in terms of labor, equipment, materials, and user delays. Therefore, the advantages of managing the activity effectively can be significant. There have been a number of studies over the years to identify the most cost-effective ways to manage patching, among other maintenance activities. Some of those documents that relate to management programs are summarized here.

### Management Policies, Costs, and Service Life

This section presents the results of some research efforts directed at examining various costs associated with pavement patching and the service lives of the treatments to guide management policies. Patch performance in general, from a management perspective, is included here; whereas the performance of particular patching materials is discussed later. Management considerations of when and how to patch a pavement are also discussed.

Prior to the SHRP research described earlier, one of the most comprehensive research efforts on pothole patching was directed by Anderson and Thomas in Pennsylvania. They evaluated pothole patching practices, equipment, and labor productivity to review PennDOT's patching management through several projects (*15–17*). One result of this effort was the adoption of a policy to "do-it-right" the first time. The researchers found that using the throw-and-go technique cost approximately three times as much as semi-permanent patches, although the latter take more time to install. The throw-and-go patches typically did not last long and had to be patched repeatedly, increasing costs and inconvenience to the travelling public. The study also concluded that material costs are a relatively small percentage of the total repair cost; therefore, using more expensive, higher quality patching materials could be justified. Based on the research findings, the authors developed a guide for patching for use by PennDOT maintenance personnel (*17*). This guide included detailed procedures for marking, cutting, cleaning, tacking, filling, compacting, and sealing the patch. Recommendations were also provided on the types of equipment to use for maximum productivity and longevity of the patch. A paper by Thomas (*18*) described a procedure for evaluating the efficiency of different devices for cutting the patches based on the cutting rate and productivity.

Citing a need to evaluate the service life of various maintenance activities in order to incorporate maintenance activities into the pavement management system, Feighan et al. (*19*) researched the costs and service lives of these treatments in Indiana in 1986. This information was deemed essential to allocate maintenance funds, identify the most cost-effective procedures, explore how changes in procedures or materials affect longevity, enable planning for future maintenance requirements, and more. One of the activities studied was shallow patching on asphalt and concrete pavements (see chapter five). Surveys and interviews of subdistrict maintenance personnel across the state were used to estimate service life. Records from maintenance crew cards and previous research were used to estimate time requirements and costs. Shallow patching using hot mix, cold mix, cold mix with fibers, and fiber mix heated in a Portapatcher were evaluated. The service lives of these various materials and procedures were compared on roadways that were otherwise in good, fair, and poor condition. In general, hot mix was found to have superior performance in all cases, and cold mix was less effective. Patches placed on better performing roads also lasted longer. However, it can be noted that these patches were typically placed under the worst conditions and improved materials have been developed since the 1980s. Heating the fiber mix improved the workability and led to better performance than using cold fiber mix (*19*).

For pavement repairs to be efficient technically and financially, it is important to place the right treatment on the right road at the right time. Specifically, if a roadway is scheduled for replacement or rehabilitation within a few years, extensive semi-permanent or permanent patching may not be justified. When performed properly and at the appropriate time, patching need not be a temporary fix, but can be an important component of a pavement management system, provided good quality materials and installation techniques are used. Good patching can be an investment in the pavement life (*20*).

In a survey of 35 state highway agencies (SHAs) conducted by Peshkin and Hoerner in 2005 (*21*), the most common approach for selecting a preventative maintenance treatment was "engineering judgment" (28 responses), followed by a selection matrix or decision tree based on pavement distresses (21 responses). This suggests that although many SHAs have a mature system established for decision making, several are relying on past experience and judgment. Although this survey dealt with preventative maintenance in general, the same could be said of patching in particular, as the survey for this synthesis shows (chapter three). Peshkin and Hoerner also noted that the use of pavement management systems, attention to maintenance, and emphasis on pavement performance were all increasing (*21*). These factors also favor increased scrutiny of pavement patching and incorporation of patching activities into overall pavement maintenance programs.

Despite the continued reliance on engineering judgment, the use of standardized guidance, such as distress identification manuals, is considered imperative in order to provide a consistent, uniform basis for applying treatments. Many states have developed manuals to guide condition ratings. For example, in 2009, the Indiana Department of Transportation (INDOT) recognized that its pavement condition data collection manual was limited owing to a lack of standardized visual methods, measurement methods for severity and extent, and information on causes of each distress. Knowledge of the causes and mechanisms of distress was identified by INDOT as an important factor in selecting appropriate pavement treatments. It also acknowledged that an identified pavement distress often has more than one possible cause. Treatment selection without a precise distress diagnostic can result in improper treatment, which may be ineffective in terms of performance and financial value (*22*). Therefore, INDOT developed detailed treatment guidelines on pavement preservation techniques that cover partial-depth patching on concrete pavements. Patching on asphalt pavements is not included because INDOT does not consider this a preservation technique (*22*).

#### Energy and Cost Considerations

Another study in Indiana investigated the fuel consumption associated with equipment used for several maintenance activities. Shallow patching was found to be second only to cleaning and reshaping ditches in fuel consumption. (Snow and ice removal was not considered.) The researchers concluded that significant fuel savings could be realized by improving the identification of routine maintenance needs and the effectiveness of the maintenance activities to prevent further damage and subsequent re-treatment (*23*).

Energy savings were also identified by increasing the use of pavement preservation techniques. Saito et al. (*24*) studied the performance of shallow patches and found that the need for shallow patching was reduced in the spring when more sealing had been performed before the preceding winter. The report indicated that the department could realize energy savings through reduced fuel consumption and there could be other benefits, such as reduced pavement damage, improved safety, and lower vehicle operating costs for the public (*24*). This study emphasized the need to coordinate patching activities with other pavement maintenance, such as sealing, as part of an overall pavement management system.

#### Outreach

Another aspect of managing patching operations is public outreach. Informing the public of upcoming patching operations can alert them to potential traffic delays, which may lead them to choose alternate routes. It also lets the public know that maintenance crews will be operating in the right-of-way, and these messages frequently urge the public to slow down for safety (*25*). This can improve safety for the workers and the traveling public, which is a primary concern in managing roadway operations. Educating the public about the needs and benefits of patching helps them appreciate the importance of the work and, hopefully, instills tolerance. PennDOT has developed a series of cards for distribution to the public to explain the importance of various maintenance activities, including patching (*26*).

Outreach to the public also sometimes takes the form of recruiting drivers to help spot problems. Since 2009, the District of Columbia has had an annual program called "Pothole-palooza." This public relations campaign establishes ways for the public to notify the District Department of Transportation (DDOT) of potholes by phone, smartphone application, e-mail, online, Twitter, and Facebook. Residents can track the progress of filling potholes online (*27*). In 2014, the department filled nearly 12,000 potholes with the public's assistance, up from around 4,000 holes filled in 2013 (*28*). During the campaign the DOT adds crews to enable a faster response time (*27*).

New York City also provides a web-based method for the public to report potholes. The site displays a tally of the number of potholes patched since the beginning of "pothole season"; over the course of the 2013 fiscal year, nearly 250,000 potholes were filled (*29*).

The Missouri DOT initiated a "Missouri Pothole Patrol" campaign in an attempt to encourage quick repair of potholes. The districts in the state compete to see how many potholes they can repair properly during the campaign. The winning district gets a small monetary award to spend on materials and equipment (*30*).

## PATCHING ASPHALT PAVEMENT SURFACES

This section summarizes the findings of the literature review related to patching pavements surfaced with asphalt mixtures. The results are presented in the categories of Materials and Testing, Techniques and Equipment, and Performance, which includes some discussion of cost-effectiveness. As with the literature on management of patching programs, there is considerable overlap in the topics covered in individual papers; for example, much of the literature reporting on materials used for patching also discusses the performance of those materials.

### Patching Materials and Testing

Many states have specifications for locally produced patching materials (as opposed to commercial, proprietary mixtures) or use some of their standard hot mix paving materials, when available. Examples include California (*31*), Indiana (*22*), and Pennsylvania (*17*). In general, clean, angular aggregates are recommended in these specifications for use in producing patching mixtures. The choice of the binder varies; some form of asphalt binder is typically used. Table 3 summarizes several of the state specifications reviewed in this synthesis, some of which focus on the binder used.

The Indiana guidelines (*22*) note that the aggregate size in the hot mix used should be related to the depth of the patch for semi-permanent repairs. If the aggregate size is too small relative to the depth of the patch there is a greater chance of rutting or displacement. If the aggregate size is too large, the material may not be adequately compacted, or seated, into the hole. It is therefore recommended that base material be used for shallow patches 3 to 6 in. deep, and surface mix for patches between 1.5 and 3 in. deep. Intermediate mixes may also be used for patches in the 2 to 5 in. range. For deep patches in asphalt pavements, INDOT recommends compacting the patching material in lifts and using surface mix on the top lift. These requirements are similar to those used in many other states.

In 2001, the New Jersey DOT published a research report exploring different patching materials, following the SHRP research protocols. In addition to testing patching materials, it also looked at tests for quality assurance and different patching methods, including throw-and-roll, semi-permanent, spray injection, and edge sealing of throw-and-roll patches. The research objectives were addressed through a literature review, laboratory testing, and field trials (*32*).

The lab tests included tests of stability, adhesion/cohesion, durability, workability, and storageability. In addition to conventional asphalt tests such as resilient modulus and Marshall stability and flow, and binder tests such as penetration and viscosity, two relatively new methods used in the SHRP research were used to evaluate the New Jersey materials. These were the blade resistance test for workability and the rolling sieve test for cohesion. The study concluded that the

TABLE 3
EXAMPLES OF MATERIALS SPECIFIED BY STATE DOTs FOR PATCHING FLEXIBLE PAVEMENTS

| State | Relevant Repair(s) | Recommended Material(s) | Material Selection Guidance |
|---|---|---|---|
| ID (*34*) | Hand patch potholes<br>Deep patch (and base repair) | Asphalt cement<br>Cutback asphalt<br>Asphalt emulsion | After consultation with the District Maintenance or Materials Engineer |
| KY (*35*) | Pothole patching<br>Bituminous patching (shoulders) | Bituminous mix<br>Liquid asphalt (optional) | No guidance |
| WA (*36*) | Patching | HMA (e.g., asphalt concrete Class B)<br>Asphalt pre-mix (cold mix)<br>Fiber-reinforced “winter mix” | Class B is recommended where possible; no specific guidance. |
| CA (*31*) | Patching and edge repair | Hot mix asphalt (HMA)—preferred<br>Cold mix asphalt—temporary only<br>Aggregate/asphalt emulsion combinations<br>Special patching mixtures | Generally HMA materials used to Caltrans DGAC specs. However, the mix type used may vary according to traffic conditions. |
| MT (*37*) | Surface repair<br>Surface patching-hand | Plant mix<br>Emulsions<br>Proprietary (cold weather) mixes | Choice of materials is dependent on distance from the source of materials to the job, time of year, and the size of the job. |
| TX (*38*) | Potholes | Medium-Curing Cutback Asphalt (MC-800)<br>Special cutback material (SCM I and II)<br>Polymer-Modified Emulsified Asphalt (AES-300S) | No guidance |
| MN (*39*, *40*) | Potholes | Cold mix (2381)<br>Spray injection<br>Hot mix 2350LV; Type 5<br>Slurry<br>Mastics<br>Microseal material | Repair type; weather; equipment (see Table 6.1) |

DGAC = dense-graded asphalt concrete.

blade resistance test did not provide any meaningful results and the rolling sieve test did not correlate with field performance (*32*). Dong et al. (*33*), on the other hand, recommended the rolling sieve test at 25°C after compacting specimens with 15 blows of a Marshall hammer as a means to assess patching mix cohesion in a study for the Tennessee DOT.

The materials evaluated in the New Jersey study included QPR 2000, UPM, I.A.R., Wespro, SuitKote, and PermaPatch. Although some of these materials did have different performance in terms of specific behaviors, such as dishing, edge disintegration, and loss of material, overall the materials performed similarly. Based on this, the researchers recommended using cost as the determining factor in selecting one of these materials to use for patching (*32*).

The Texas DOT sponsored a research effort to develop a mix design method for what they termed "homemade" patching mixtures, meaning cold patching materials that could be produced locally (*41*). Locally produced mixtures were compared with six packaged, commercial patching materials. A fairly unique set of tests was used in the evaluations. In the lab, a cold patch slump test was used to assess workability, and Hamburg wheel tracking and a less severe Texas stability test were used to assess stability. To assess the ability to store the bagged materials for a period of time, a drop test was developed to drop the bags and determine if the bags split. If the bags do split during handling, material could spill and volatiles could be lost upon exposure to air. Another unique feature of this research was the use of accelerated pavement testing to evaluate patch performance. The Model Mobile Load Simulator (MMLS3) was used to test materials in the field. Field test sections on roadways in Lubbock, Lufkin, and other locations were also evaluated (*41*).

Based on the various test results, the research team recommended performance-based specifications for cold patching materials. The specifications require testing workability using the cold patch slump test and stability in the Texas stability test. Upon successfully passing those two tests, the material would be further evaluated under the MMLS3 (*41*).

Another example of an attempt to develop a local patching material is a study by the California DOT (Caltrans) that attempted to modify an existing dense-graded patching material for use in patching open-graded pavement surfaces. The drainage paths through an open-graded mix can be disrupted by the use of a dense-graded patching material. In this study, a dense-graded urethane polymer-bound patching mix was modified to make it free-draining (i.e., open-graded). The urethane-based patching mix produced was workable and drainable but not durable (*42*).

Studies have also investigated the use of unconventional materials for pavement patching. For example, a study at the Chelsea Center for Recycling and Economic Development looked at using recycled rigid plastic aggregate in a lightweight cold patching mix (*43*). While the findings were favorable, the material is not known to have been used except experimentally. A study in Minnesota explored the possibility of using taconite mine tailings as aggregate for pavement applications; the report indicated that the use of taconite in asphalt patching materials was an on-going investigation (*44*). An article in *Better Roads* (*45*) indicates the technique of using microwave heating with taconite aggregates has now been commercialized.

A Texas study by Estakhri and Button (*46*) aimed to develop ways to measure the workability of cold patching mixes. The study compared the use of unconfined compression tests and triaxial compression tests on lightly compacted samples of the patching materials. These tests were performed before and after laboratory aging in a forced draft oven at 120°C for 48 or 96 hours. The results suggested that the two types of compression tests gave similar results; therefore, either one could be used to assess workability. The aging for 48 hours was found to best simulate six months of field aging. Criteria for the unconfined compression test, which is simpler to perform than triaxial testing, were established at a maximum of 200 kPa in an unaged condition and less than 1000 kPa after aging (*46*).

#### Patching Techniques and Equipment

The Caltrans Division of Maintenance prepared a maintenance technical guide in 2008 (*31*), which includes descriptions and diagrams of the causes of potholes and recommendations on patching practices. It endorses using temporary patches when necessary followed by semi-permanent patches using tack and edge sealing. The manual states that merely filling a pothole is not enough to stop further damage around or inside the patched area. Better performance is achieved when the hole is cut back to sound pavement. Compaction of the patching material is also critical to good performance. The manual contains valuable advice for troubleshooting patching problems, as shown in Table 4 (*31*).

A process for preparing holes for patching was reported in the journal *Public Works* in May 2004 (*47*). This was developed through a study, conducted at Brigham Young University, that compared the performance of straight, vertical cut edges on a patch with the rougher surface texture created by a device called an "Asphalt Zipper." This cutting device produced an "angular scarification" on the cut edge (*47*). Cores taken one month after patch placement were used to compare the bond strength at the interface of vertical cut faces and the "zipped" face. The results showed that the rough surface texture yielded much higher bond strengths because of the increased mechanical interlock between the patch and the surrounding pavement (*47*). This may be considered to be similar to findings on concrete pavements that chipping and patching, which produces a rough surface, can perform better than sawing and patching.

Another equipment innovation that has found fairly widespread adoption is the spray patcher. Many studies since the days of SHRP have evaluated the use of this equipment.

TABLE 4
COMMON PATCHING PROBLEMS AND RELATED SOLUTIONS

| Problem | Solution |
|---|---|
| Patching Material Does Not Adhere to Hole | • Ensure the hole is cleaned properly and not too wet.<br>• Ensure sufficient tack coat is applied.<br>• Use a self-setting cold mix when holes cannot be dried properly.<br>• Ensure the patch is solid before trafficking.<br>• Dust patch surface with sand or small aggregate.<br>• Wait for better weather.<br>• Do not use cutback-based cold mix (unless a temporary repair is being done).<br>• For HMA patches, allow to cool before traffic is allowed over the patch.<br>• Ensure required compaction is achieved. |
| Surface Flushing/Bleeding | • Reduce asphalt or emulsion content in the mix.<br>• Reduce tack coat application.<br>• Allow longer time before trafficking.<br>• Ensure the gradation of the aggregate is appropriate. |
| Uneven Surface | • Ensure cold mix is workable.<br>• Ensure HMA is at the right temperature for placement and compaction.<br>• Ensure adequate compaction is achieved. |
| Loss of Cover Rock in Seal Coat Patches | • Ensure surface is clean.<br>• Ensure correct emulsion content is sprayed.<br>• Ensure aggregate is spread while emulsion is still brown.<br>• Ensure emulsion is broken before traffic is allowed.<br>• Allow longer cure time before traffic. |
| Traffic Compacts Mix to Below Edge of Hole | • Ensure finished hole is overfilled 0.1 to 0.2 in. (3 to 6 mm).<br>• Ensure adequate compaction is achieved.<br>• Ensure mix is workable at application temperatures.<br>• Allow longer time before trafficking. |

After *Maintenance Technical Advisory Guide, Vol. 1—Flexible Pavement Preservation* (*31*).

Although FHWA considers spray patches temporary (*10*), some states consider the patches almost as good as semi-permanent patches (see the survey results in chapter three). The Caltrans maintenance manual also mentions spray injection patching as a promising technology, although Caltrans did not use spray patchers at the time and their use by the agency is still limited (*31*).

An article in the journal *Better Roads* in 2004 described the successful implementation of spray patchers by some agencies (*20*). According to the article, the District of Columbia had purchased four of the devices and found that they were able to repair potholes with smaller crews and less equipment; one self-contained spray patcher and a crew of three could replace two or three vehicles used for hauling patching mix, crew, tools, and traffic control devices. The same article reported that South Carolina tested spray patchers in 1997 and was so favorably impressed that they purchased 59 of the units. It was reported that the need for repeat patching was reduced by 50% to 60% when spray injection patches were placed in South Carolina (*20*).

Another technique developed for patching operations uses infrared heat to produce a patch. One process, called HeatWurx, heats and scarifies the existing pavement around the hole, mixes in new material, and compacts the patching material into the hole. A study by Freeman and Epps in Texas (*48*) evaluated the process and the performance of 83 patches constructed with this process. The study concluded that the process did yield a well-bonded patch. Because the process produces a hot patch, it could be used in cold weather or at locations at a distance from a hot mix plant. On the other hand, concerns were expressed in the report about traffic control, because the bulky equipment requires closure of the adjacent lane; the slow production rate; and the depth of heat penetration, which was reported to be less than 2 in. (*48*).

Other investigations of heating the area to be patched to produce a better repair include the Minnesota study using taconite mine tailings (*44*). As part of that study, the authors also investigated use of a microwave generator to heat the area surrounding a pothole and the reclaimed asphalt pavement material being used to patch the hole. The process took about 50 minutes per hole, which the Minnesota DOT did not find practical at the time (*44*). The update in *Better Roads* suggests that the heating time has been shortened and the repair area can be heated in a matter of minutes (*45*). A Canadian study also looked at heating the area to be patched; in this case, infrared was used to heat and remove material around cracks before patching. The technique was reported to be successful and similar in cost to conventional crack repair (*49*).

### Performance

Patches may fail because of the materials used, installation issues, or simply because the roadway continues to deteriorate. The patches themselves may fail in a number of ways, as described by Anderson et al. in 1988 and shown in Table 5 [cited in Rosales-Herrera et al. (2007) (*41*)]. Some of the less

TABLE 5
FAILURE SYMPTOMS AND MECHANISMS

| Symptom | Failure Mechanism |
|---|---|
| *In Stockpile* | |
| Poor Workability | Binder too stiff; excessive fines or dirty aggregate; mix too coarse or too fine |
| Binder Draindown | Binder too soft; stockpiled or mixed at high temperatures |
| Stripping | Inadequate binder coating during mixing; cold or wet aggregate |
| Clumpy Mixture | Binder cures prematurely |
| Cold Weather Stiffness | Significant binder susceptibility to temperature; excessive fines or dirty aggregate; mix too coarse or too fine |
| *During Placement* | |
| Poor Workability | Binder too stiff; excessive fines or dirty aggregate; mix too coarse or too fine |
| Poor Stability | Binder too soft or excessive binder; insufficient voids in mineral aggregate; poor aggregate interlock |
| Excessive Softening (when used with hot box) | Binder too soft |
| *In Service* | |
| Pushing, Shoving | Poor compaction; binder too soft or excessive binder; significant binder susceptibility to temperature; contaminated mixture; slow curing rate; moisture damage; insufficient voids in the mineral aggregate; poor aggregate interlock |
| Dishing | Poor compaction |
| Raveling | Poor compaction; binder too soft; poor mixture cohesion; poor aggregate interlock; aggregate binder absorption; moisture damage; excessive fines or dirty aggregate; mix too coarse or too fine |
| Freeze-Thaw Deterioration | Mix too permeable; poor mix cohesion; moisture damage |
| Poor Skid Resistance | Excessive binder; aggregate not skid resistant; gradation too dense |
| Shrinkage or Lack of Adhesion to Sides of the Hole | Poor adhesion; tack coat not used or mix not self-tacking; poor hole preparation |

*Source*: Anderson et al. (1988), cited in Rosales-Herrera et al. (*41*).

common terms used in this table were defined by Prowell and Franklin (*50*) as follows:

- Bleeding or flushing—excess asphalt at the surface of the patch.
- Dishing—densification of the patch material under traffic, resulting in a depression.
- Debonding—lack of adhesion of the patch material to the sides or bottom of the patched area.
- Raveling—loss of material from the patch.
- Pushing and shoving—surface distortion resulting from instability of the patching material.

Prowell and Franklin (*50*) reported on an evaluation of 13 proprietary cold patching mixtures, four of which were already approved under the Virginia DOT's special provisions. It was believed that having more choices of patching materials—provided the performance was the same—would increase competition and lower costs. The materials were evaluated through test sections and were rated with regard to bleeding, dishing, debonding, raveling, shoving, and tracking. In addition, tests were performed in the laboratory to assess coating, stripping, draindown, cohesion, workability, and adhesion. The study found that the proprietary cold mix materials performed significantly better than a local Virginia patching mix. The rating system developed in the study could be used to compare the performance of different patching materials. They also concluded that lab tests alone could not predict the field performance and cautioned that conventional solvent extractions might yield unreliable estimates of the binder content in these cold mixes (*50*).

A study by Wei and Tighe looked at the typical service lives of various pavement preservation techniques in Canada (*51*). They found the average life span and costs of patching to be as shown in Table 6.

TABLE 6
AVERAGE LIFE AND COST OF ASPHALT PATCHING METHODS

| Patch Technique | Life Span (years) | Cost (Canadian $/lane/km) |
|---|---|---|
| Spray Injection Patching | 2 | 3,375 |
| Machine HMA Patching | 4 | 1,386 |
| Manual HMA Patching | 5 | 1,246 |
| Mill and Patch 10% | 6 | 2,450 |
| Mill and Patch 20% | 7 | 4,900 |

*Source*: Wei and Tighe (*51*).

Under the conditions in this study, spray injection was not found to be cost-effective (*51*). This is in contradiction to some states' experience and studies, but other states would agree, as discussed in chapter three.

Another Canadian study focused on developing a performance-based specification for a particular type of spray patching (*52*). In this case, dips were observed at transverse cracks on a roadway, causing a rough ride. A repair technique using spray patching was attempted to even out the ride quality by filling in the dips. Based on the improvement in ride quality, as measured by before-and-after International Roughness Index readings, the maintenance contractor would be eligible for an incentive. Overall, the technique did not substantially improve the ride quality. In many cases, the dip at the crack was still present after patching and two bumps were formed by excess patching material immediately before and after the crack (*52*).

## PATCHING CONCRETE PAVEMENTS

This section parallels the section on patching asphalt pavements and covers the same types of technical details, but specifically focuses on concrete pavements. Overall, there are more options for patching materials, more properties to consider testing, and more potential tests for materials to patch concrete surfaces than asphalt. Therefore, there appears to be more research and more literature on patching concrete pavements. Much of the literature has to do with comparisons of the performance of different types of materials in lab and field settings. Some reports also address types of repairs in the field, their performance, and most effective practices. More than 70 documents on patching concrete pavements were reviewed. Highlights of some of the most pertinent literature identified are summarized here.

### Patching Materials and Testing

As mentioned previously, there are many more options for patching concrete pavements than asphalt pavements. The possible materials available include various types of cementitious materials with or without additives, polymer materials, and asphalt mixes. Table 7 summarizes some of the material options allowed by various states. (This is not an exhaustive list, but is intended to show the range of options allowed.)

Managed by FHWA through partnerships with SHAs, industry, and academia, the Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. In 2005, the CPTP prepared a technical brief on state-of-the-art concrete pavement rehabilitation and preservation treatments, including partial depth repair (PDR). Recommended materials for PDR on pavements that are structurally sound (i.e., no significant fatigue cracking) include cementitious (including gypsum-based and magnesium phosphate concretes), polymer-based concrete, and bituminous materials. Conventional portland cement concrete (PCC) is quoted as being the most commonly used PDR material, typically providing opening times of four hours or less. The most common polymer-based materials listed are epoxy, methyl methacrylate, polyester-styrene, and polyurethane. While typically offering rapid strength gains, these materials are noted as being very expensive relative to conventional PCC. Bituminous materials are suggested as being inexpensive, widely used materials, but typically provide temporary patches only. Although no specific guidance is given, material selection is recommended to be based on available curing time, ambient temperature, cost, desired performance, and the size and depth of repairs (*53*).

A 2008 study by Clemson University, sponsored by the South Carolina DOT, identified key factors influencing the compatibility of repair materials with the pavement being patched, including modulus of elasticity, Poisson's ratio, and tensile strength; porosity and resistivity; chemical resistivity; thermal expansion coefficient; and shrinkage strain (*57*).

A variety of test methods has been used to assess those and other factors (*57*). Although those tests may be important and useful for research purposes, a review of state specifications and interviews with agency personnel conducted during this synthesis suggest that relatively few of these tests are used routinely for accepting patching materials by the DOTs.

One of the most comprehensive suites of testing is used by the National Transportation Product Evaluation Program (NTPEP). In 2009, NTPEP published its two-year report of field performance and laboratory evaluations of rapid-setting patching materials for PCC (*58*). Products suitable for consideration by the program are cementitious, latex-modified, polymer resin, magnesium phosphate, and other materials expressly designed for patching PCC pavements and bridge decks. An extensive suite of laboratory-based testing is undertaken for each material. Field test sites are also monitored for two years (*58*). NTPEP does not make recommendations, but does provide the data so agencies can draw their own conclusions.

In 1999, the University of Central Florida (UCF) undertook research funded by the Florida DOT to identify quality patching materials for the repair of spalls on concrete pavements. As part of this work, eight products, three of which were Florida DOT approved, using polymer concrete, elastomeric concrete, and cementitious mortar were studied as part of this research. Based on material compressive strengths and the fracture patterns observed in this lab-based testing, preferred patch materials were selected for accelerated performance testing. The accelerated testing was performed at UCF's Circular Accelerated Test Track (UCF-CATT)—a 15.2-m (50-ft) diameter test track. The ultimate objective of the work was to evaluate the performance of various advanced materials available on the market for partial depth repair of concrete pavements. Based on the study, UCF developed

TABLE 7
MATERIALS SPECIFIED BY STATE DOTs FOR THE REPAIR OF RIGID PAVEMENTS

| State (ref.) | Relevant Repair(s) | Material | Material Selection Guidance |
|---|---|---|---|
| ID (*34*) | Patching | High early-strength concrete<br><br>Air-entrained concrete | To comply with Idaho's Standard Spec. Book. After consultation with the District Maintenance or Materials Engineer (for volumes greater than 5 cubic yards). |
| IN (*22*) | Partial depth patching | HMA Type A<br>Concrete—Rapid-setting concrete with a non-vapor barrier bonding agent<br>Bitumen HMA with a bonding agent (AE-T) | Selection of patching materials is based on the curing time, which determines traffic opening conditions. |
| WA (*36*) | Repair/patch ing | Portland cement concrete (PCC)<br>WSDOT approved patching mortars (extended with aggregate)<br>WSDOT approved product (rebar coat) | Material performance requirements [(see section 9-20.2(1)] |
| CA (*54*) | Isolated partial depth repair | Normal concrete mixtures<br>*Specialty concretes:*<br>Gypsum-based cement mixtures<br>Magnesium phosphate cement<br>High alumina cement mixtures<br>Accelerating admixtures/additives<br>Alumina powder<br>*Specialty:*<br>Polymer concrete<br>Epoxy<br>Methyl methacrylate concrete<br>Polyester-styrene concrete<br>Polyurethane concrete<br>Bituminous—temporary fix only<br>*Bonding agents:*<br>Sand–cement grouts<br>Epoxy bonding agents | Based on available curing time, climatic conditions, material costs, equipment requirements, mixing and placing time, desired service life, and the size and depth of repair(s). Material properties, such as strength gain, modulus of elasticity, bond strength, scaling resistance, sulfate resistance, abrasion resistance, shrinkage characteristics, coefficient of thermal expansion, and freeze-thaw durability should also be included in the selection process. |
| MN (*39, 55*) | Pop-outs/ scaling<br>Partial depth repairs | Concrete (3U18)<br>Bonding/sealing grout; curing compound<br>*Small patches:*<br>Cold or hot bituminous mix<br>Proprietary asphalt mixes<br>Epoxy or other modified concrete | No guidance |
| MT (*37*) | Temporary patching<br>Permanent patching | Plant mixed asphalt—temporary patches only<br>PCC made (with high early strength cement)<br>Rapid setting proprietary products | Consult material spec for PCC mix design. If using proprietary products, consult product brochures. |
| TX (*38*) | Spalling | Rapid-Set Concrete (DMS-4655)<br>Polymeric Patching Material (DMS-6170) | No guidance |
| WY (*56*) | Spalling (PDR) | High-alumina cementitious mortar<br>Epoxy Resin<br><br>Bonding agents (as required) | Preapproved by the Materials Program and meeting performance spec (Table 810.1.2-1). Injection Material to ASTM C 881, type I, grade 2; Bonding compound to ASTM C 881, type V, grade 2 |

new guidelines for laboratory testing and material placement techniques to enable appropriate material use and field construction practices (*59*).

The accelerated testing showed that after a total of 500,000 repetitions of a 44.5 kN (10,000 lb) load, no signs of major cracking were observed on any of the patches; patch de-bonding was the critical failure mechanism encountered. The elastomeric materials exhibited a higher tendency to fail in comparison with cementitious materials. Notably, the two feather-edged cementitious patches performed well in this study, indicating that a conventional square-cut procedure before patching may not be necessary with appropriate high-strength, fast-set patching materials (*59*).

In 2005, the Iowa DOT undertook a research program to assess the appropriateness of using blended cements for concrete patching operations (*60*). The impetus for this work was that while many ready-mix producers exclusively made use of blended cements in construction, Iowa DOT specifications did not permit its use in patching operations because of their assumed slow strength gain. (Iowa DOT patching specifications required opening at 5 hours on 2-lane or 10 hours on 4-lane pavements.)

Ordinary Type I/II portland cements and Type I(SM) blended portland cements were investigated as part of the research. Although the compressive strength gain of the mixtures with Type I(SM) cement was slower than that of the mixes with ordinary Type I cement, all the results were in excess of the pavement opening requirements. At the curing temperatures used in this research, the time difference to achieve the required strength between Type I(SM) and Type I/II cements was approximately one-half hour (*60*).

In 2004, the Wisconsin DOT (WisDOT) published findings of laboratory testing of PCC patch materials modified to reduce or eliminate shrinkage (*61*). In 2001, WisDOT evaluated several different rapid-setting patch materials on an existing rehabilitation project, all of which exhibited microcracking and de-bonding caused by shrinkage within one year. Of the patch materials originally evaluated, only three met all of WisDOT's requirements for rapid-set concrete patch materials: a proprietary material (Tamms Speed Crete 2028) tested at two different coarse aggregate extension ratios and the Minnesota DOT 3U18 concrete mix (modified with Type III cement in lieu of Type I) (*61, 62*). The study led to recommendations to use appropriate shrinkage-reducing admixtures and curing compounds to enhance the performance of high early strength patch repairs. Also, rather than specifying high strength at a very early age (300 psi at 3 hours), it was recommended that this strength level be reached after 24 hours. This would allow use of more conventional repair materials (such as a modified Minnesota DOT 3U18 patch material) providing suitable levels of performance and cost (*62*). In addition, the study found that the ambient air temperature, temperature of the surrounding concrete, and, in particular, wind speed, have a dramatic effect on the rate of evaporation and rate of hydration of concrete patch materials. It was recommended that tighter controls be placed on allowable environmental conditions at the time of placement of concrete patch mixes (*62*).

In 2009, the U.S. Army Engineer Research and Development Center reported on a research program undertaken to determine rapid-setting material suitability for expedient pavement repairs based on both laboratory and full-scale traffic tests (*63*). The primary objective of the study was to assess commercial, off-the-shelf, rapid-setting, cementitious-based materials currently on the market and to develop appropriate laboratory selection criteria that could be used for selecting expedient repair materials for PCC airfield pavements. Nine different repair materials (belonging to one of four types of base materials: polymeric, ultrafine portland cement, magnesium phosphate, and high alumina) were assessed (*63*).

Laboratory testing was conducted initially to determine the unconfined compressive and bond strengths of each material. Subsequently, in-field traffic testing was undertaken on 1.5-m (5.0-ft) square repair areas prepared by saw-cutting and removing the surface of an existing PCC pavement. In terms of performance, all the repair materials met the minimum traffic level with little to no deterioration. Traffic was then continued to quantify the point at which failure occurred as well as the resultant failure mechanism. Only four repair materials failed to meet the minimum performance level. When failure did occur, the predominant failure mechanism was cracking (*63*).

Based on historical data and the testing undertaken, a correlation between laboratory test results and in-field performance under trafficking was established. The proposed laboratory testing protocol for selecting rapid-setting patch materials is shown in Table 8. Although developed primarily for airfield pavements, the authors suggest that these guidelines can easily be applied to other pavement types (*63*).

The previously mentioned study by Clemson University (*57*) noted that a wide variety of rapid-set patching materials are available in the industry for repair of concrete, as shown

TABLE 8
PROPOSED MINIMUM LABORATORY-BASED TESTING PROTOCOL FOR SELECTING RAPID-SETTING PATCH MATERIALS

| Property | ASTM | Requirement |
|---|---|---|
| Compressive Strength | C39 | ≥3,000 psi at 2 hours |
| Flexural Strength | C78 | ≥350 psi at 2 hours |
| Bond Strength | C882 | ≥850 psi at 1 day (repair bonding to OPC mortar) |
| | | ≥1,000 psi at 1 day (repair material bonding to repair material) |
| Volumetric Expansion | C531 | ≤$7 \times 10^{-6}$ in./in./°F (testing begins at 3 days)[a] |
| | C157 | <0.03% (testing begins at 4 days)[b] |

*Source*: Priddy et al. 2009 (*63*).
[a] Test at temperature similar to expected field conditions.
[b] Continue testing according to ASTM requirements following the early age tests.

in Table 7. However, the selection of an appropriate material for a particular repair job is challenging as these materials possess a range of physical and mechanical properties and definitive criteria for establishing the compatibility between repair materials and substrate concrete are not adequately defined. Improper selection of repair material, without investigating the compatibility between repair materials and substrate concrete, is a common reason for failure. Therefore, compatibility between eight repair materials, which were on the approved list of the South Carolina DOT, and a typical substrate concrete was investigated. Based on the findings from this study, it was concluded that although the properties of repair materials are important from an operational standpoint (i.e., opening the repaired section to traffic), these properties do not correlate well with field performance of the repaired composite sections. As a result of the work undertaken, it was found that flexural strength testing of composite beams better characterized compatibility between repair materials and the substrate concrete (*57*).

In 2003, the Oregon DOT published a spreadsheet-based concrete patching guide to help maintenance personnel determine which product to use. Although state DOT-produced lists of qualified products exist, these typically do not provide information to assist personnel in selecting an appropriate product for a particular job. The tool matches the attributes of specific products to the needs of a particular patching job. An output report is generated providing a list of qualified and conditional products (which require field experience before being listed as qualified) from the state Qualified Products List (*64*).

To use the guide, a user checks off on a list statements that describe the requirements for a particular patching job. The patch descriptors include what material the patch will be in contact with, the orientation, size, needed working time, amount of time before the patch is exposed to further construction or traffic, need for formwork, and other variables. The selection tool compares the user's requirements with the attributes of the various patching materials to find matches. It can be noted, however, that the tool was developed based on feedback received from questionnaires completed by material manufacturers and not on independent performance data or testing (*64*).

Despite all of the tests recommended in the research reports summarized here, a review of state specifications shows that only a few test methods are used routinely by the DOTs to approve or accept patching materials.

#### Patching Techniques and Equipment

In August 2005, FHWA published a checklist series, one of which was *Partial-Depth Repair of Portland Cement Concrete Pavements* (*65*). This checklist was created to guide state and local highway maintenance and inspection staff in the use of innovative pavement preventive maintenance processes. The document is brief and provides a checklist covering the key issues relating to:

- Preliminary responsibilities,
- Document review,
- Project review,
- Materials checks,
- Equipment inspections,
- Weather requirements,
- Traffic control,
- Project inspection responsibilities,
- Cleanup responsibilities, and
- Common problems and solutions.

Last updated in July 2011, the FHWA's concrete technology team has published extensive guidance (*66*) on PDRs. With PDRs defined as repairs involving removal of deteriorated concrete limited to the top third of a slab's thickness and replacing it with appropriate repair materials, guidance is given in the following areas:

- Selection of candidate projects (based on pavement condition and climatic conditions),
- Design considerations (including repair boundaries and selection of materials),
- Construction procedures (including repair identification, preparation, placement, and finishing),
- Opening to traffic,
- Performance considerations, and
- Cost implications.

The key output from this document is a generic guide specification for PDRs (*66*).

Another useful guide document was published by the National Concrete Pavement Technology Center at Iowa State University in April 2012 (*67*). This document, *Guide for Partial-Depth Repair of Concrete Pavements*, provides information about selecting, designing, and constructing successful PDRs that extend as much as half the depth of concrete pavement slabs. A key departure from previous best practice guidance is the depth of recommended repair, which has increased from one-third to one-half of the pavement depth. In recent times, many deeper PDRs have lasted for 10–15 years or as long as the existing pavement.

One technique for PDR construction uses milling machines to excavate the area to be patched. In 1980, Minnesota implemented a modified partial-depth repair on a spalled section of pavement that extended deeper than the top one-third of the slab. Milling machines were used to remove the concrete in the distressed area and form a tapered edge around it. The milled surface was cleaned and a cement grout was applied; then a cement-based repair material was applied. In the 1990s, Minnesota's cost-effective method was copied in Wisconsin and Michigan. In the 2000s, Kansas, Missouri, Colorado, and South Dakota adopted similar milling approaches to PDRs.

By using milling equipment and durable concrete mixtures, these states have successfully demonstrated the use of PDRs in pavements where deteriorated areas extend from one-third to one-half the slab depth. As a result, today partial-depth repairs are used for more joint repairs and at less cost than traditional full-depth repairs (*67*).

The Concrete Pavement Technology Program brief (*53*), mentioned in "Patching Materials and Testing", suggests that PDR is a suitable strategy for addressing transverse or longitudinal joint spalling caused by incompressible or weak concrete and localized surface defects. Distress types not considered as candidates for PDR include crack spalling, joint spalling caused by dowel bar misalignment, lockup, D-cracking, reactive aggregate, or other materials-related deterioration. If PDR is selected as the repair technique, it is important that the following points be considered (*53*).

- Repair dimensions should be selected by "sounding" a pavement using a hammer, solid rod, or chain, and deterioration boundaries marked. A square or rectangular shape is recommended and areas less than 0.6 m (2 ft) apart should be combined into one repair area. To ensure effective performance, generally the area marked for removal should extend 50–150 mm (2–6 in.) beyond the weakened pavement in each direction. Recommended minimum PDR dimensions are 300 mm (12 in.) long, 100 mm (4 in.) wide, and 50 mm (2 in.) deep.
- Deteriorated concrete should be removed by sawing using a diamond-bladed saw and chipping out with a light hammer weighing less than 14 kg (30 lb). Alternatively, a milling machine, operated either transversely across joints for small, individual spalls or longitudinally along the length of joints for larger repair areas, is recommended.
- After removal of defective concrete, repair areas should be cleaned to remove all loose particles, dirt, and debris that could inhibit bonding. This is generally accomplished by sand-blasting, followed by air-blasting to remove any residue.
- For PDRs placed at joints, a strip of compressible material must be placed in the joint to accommodate horizontal movements, to prevent patching material infiltrating the joint, and to re-establish the joint. Inserts should extend 25.4 mm (1 in.) below and 76 mm (3 in.) beyond repair boundaries.
- For most repair materials, application of a thin layer of a cementitious grout bonding agent is recommended before patching. The bonding agent is placed after the repair area has been cleaned and immediately before the placement of the repair material.
- In terms of patch material placement and finishing, it is recommended to slightly overfill to allow for a reduction in volume during consolidation. Material should be adequately consolidated with a small spud vibrator to remove entrapped air. A stiff board can be used to screed repair surfaces to ensure surface alignment and bonding with the existing pavement. Repair surfaces should be textured to match that of the surrounding slab (see Figure 12).
- Proper curing is very important to prevent rapid moisture loss from PDRs. Commonly a white-pigmented curing compound would be applied as soon as the water sheen has disappeared from the repair surface. Typical curing compound application rates are about 2.5–4.9 $m^2/L$ (100–200 $ft^2/gal$).
- For early opening to traffic, or in cold-weather conditions, insulating blankets may be needed to help accelerate rates of strength gain.

In 2010, Hammons and Saeed published findings of research undertaken to investigate selected methods and equipment for expedient spall repairs constructed with rapid-setting materials (*68*). With a focus on airfield pavement applications, the main objective of the work was to examine various methods of excavating concrete and placing a commonly used rapid-setting repair material in 2 $ft^2$ x 4 in. deep spalls within 15 minutes or less. Spalls were prepared using the following methods:

- Saw cut and portable pneumatic 30 lb jackhammer (baseline or current standard),
- Saw cut and a hydraulic breaker on a skid steer tractor,
- Multiple-blade gang saw with saw spacing at ¾ in.,
- Multiple-blade gang saw with saw spacing at 1½ in., and
- Cold planer attachment for a skid steer loader.

When compared with the use of a portable pneumatic 30 lb jackhammer (the standard Department of Defense spall repair excavation method), each of the other methods evaluated offered significant improvements in production rate. The most efficient method was using a cold planer that, on average, was approximately 58% more efficient than the jackhammer method. Of the methods evaluated, only the cold planer could meet the requirement of excavating the patch in 15 minutes or less (*68*).

The study recommended that the cold planer method be adopted as a standard method of preparing spalls for placement of a rapid-setting spall repair material. Although the time to prepare a spall depended on the characteristics of the spall and the skill of the operator, use of this equipment required approximately half the time to prepare the spall compared with manual jackhammer-based approaches. Spalls prepared with this method retained superior bond strength after significant trafficking and were expected to provide superior performance compared with those prepared using other conventional methods (*68*).

Although partial depths repairs are the subject of much of the literature on field performance and experience, deeper distresses can also be addressed by concrete patching. In 2011, Yuan and Liu reported research undertaken to assess an appropriate upper size limit for the repair of PCC corner breaks with asphalt concrete. As long as safety and ride quality are not compromised; asphalt concrete patching was proposed by the authors as an appropriate temporary measure to prevent further moisture penetration and performance defects (*69*).

Beginning in 2007, a study was undertaken by Yuan and Liu of the Xiangtan–Leiyang Expressway, where asphalt concrete was applied to 11,441 broken slab corners. The total asphalt patching area was 26,015 $m^2$, with the average patch area of a single broken corner equaling 2.27 $m^2$. Based on statistical and equivalent annual cost analysis, an upper patching area limit of 2.66 $m^2$ was proposed. Beyond this value, full-depth slab replacement was considered to be a more appropriate investment of maintenance funds. Furthermore, the authors pointed out that despite the suitability of asphalt for corner break repair, because of its perceived temporary, small-scale applicability, limited corresponding construction specification guidelines had been developed by local highway agencies. Suitable guidance, including construction process, materials, and optimum patching areas, was recommended (*69*).

#### Performance

In 1999, research findings were published by the Mississippi DOT aimed at examining the relative performance of proprietary polymer concrete-based products (RESURF CR and RESURF II) against a standard asphalt-based repair approach (*70*). In total, 43 punch-out deteriorations on I-55 were repaired using these materials to restore an acceptable riding surface. Rather than adopt the traditional approach of removing failed concrete, re-establishing reinforcing steel as required, and patching with new concrete, the polymer concrete products were used to cement broken concrete pavement pieces together in situ. RESURF CR—a variable viscosity, low shrink, pourable polyester compound designed for cracks of up to 0.5 in. (12.7 mm)—was used to cement the pieces. RESURF II—a general performance polymer concrete consisting of a styrene diluted modified polyester resin with a select aggregate blend—was used to restore a smooth riding surface to patch areas after application of RESURF CR.

In summary, the evaluation found that the proprietary materials did not prove to be a long-term solution for punch-out repairs, requiring more effort and time than temporary repairs using asphalt. The proprietary repairs were more than four times as expensive as removing and replacing the concrete pavement. Based on visual inspections and pavement deflection measurements, 91% of patches surveyed were rated "good" after one year of service, 37% were rated "good" after two years of service, and only one patch lasted three years. In this instance, the use of particular proprietary patch materials was not recommended for punch-out repairs intended to last longer than one year (*70*).

In 2007, Chen et al. reported on field evaluations of various patch materials used for partial-depth repair of concrete pavements (*71, 72*). Of the numerous patching materials available on the market, Markey et al. (*73*) performed extensive laboratory and field investigations of ten patch repair materials that have been used in Texas and concluded that polymeric materials performed most favorably. Based on these findings, two types of polymeric patch materials (both polyurethane and epoxy-based resins) were used to repair spalls and cracks on US-290, SH-6, and US-75. The repair materials were used to repair spalls in both continuously reinforced and jointed concrete pavements (CRCP and JCP) and performance was recorded up to a period of six years. Performance was inferred from simple visual observations, distress rating, and ride quality measurements (*71*).

The study found that repairs placed using both chip-and-patch and saw-and-patch methods have performed satisfactorily over six years. As recommended by FHWA based on the SHRP research, this study confirmed that chip-and-patch is a satisfactory approach provided all delaminated areas of concrete are completely removed. The results showed that polymeric patch materials have performed well in both CRCP and JCP. In particular, the polyurethane-based product was effective at bridging transverse cracks in the CRCP's vertical direction and resisted the propagation of these cracks through the concrete pavement while maintaining a good bond to the substrate concrete. The use of polymeric-based PDRs has dramatically decreased the frequency of spall repairs undertaken by Texas DOT's Houston District. Furthermore, this study reported that, compared with full-depth repair, PDRs utilizing polymeric patch materials offer a much more time and cost-effective maintenance strategy (*71*).

CHAPTER THREE

# U.S. STATE SURVEY RESPONSES

This chapter summarizes the responses to the U.S. survey as well as follow-up interviews and communications. A total of 48 states plus the District of Columbia responded to the survey, for a response rate of 96.1%. The responses are discussed and many are shown graphically in this chapter. A copy of the U.S. survey is provided in Appendix A, and the tabulated survey responses are in Appendix B.

This chapter covers management and policies regarding pavement patching such as:

- What distresses are suitable for patching;
- What triggers patching activities;
- Whether the agency has specifications, plans, or guidelines for patching;
- Any quality control and/or quality assurance (QC/QA) requirements;
- When contracts are used in lieu of state workforces;
- Whether patch locations and performance are monitored;
- Traffic management for different patching activities and types of roadways; and
- Other factors that apply to patching both pavement types.

In addition, the survey addressed materials used for patching asphalt and concrete pavements, equipment used, and other materials and operations topics. The survey also asked about research and resource needs. These responses are reported in later sections of this report.

## MANAGEMENT-RELATED SURVEY RESPONSES AND INTERVIEW FINDINGS

The survey questions relevant to the management of patching operations are presented here along with summaries of the survey responses. In some instances, these responses have been elaborated upon based on follow-up communications with a limited number of agencies.

The first survey question asked if the respondents consider pavement patching to be a major component of their organization's maintenance operations. In response, 43 of 49 respondents (85.7%) said that it was, five (10.2%) said it was not, and one (2.0%) did not answer that question (in addition to the two states that did not submit a survey response). Patching is clearly important to most states, as illustrated in Figure 13. Those respondents that did not believe it was a major component of their operations were in Arkansas, California, Florida, Massachusetts, and Nevada—most in predominantly warmer regions of the country.

In an attempt to get an idea of the scale of the state patching programs, the survey asked what the average annual extent of patching repairs was in their state. A variety of measures was offered to make answering the question as easy as possible; these included the number or area of patches per mile, volume of patching material used, and percentage of the maintenance program. Most of the states that responded provided either a percentage of the maintenance budget or an overall cost. Arkansas reported that costs for patching amounted to only 0.10% of the state maintenance program; it is 0.5% in Nevada. Of those states that believe patching is a major element, estimates of the percentage of their maintenance program ranged from 2% ($1.5 million out of a $75 million maintenance budget) in New Hampshire to as much as 40% in North Dakota and 50% in the District of Columbia. Percentages between 1% and 5% were more typical. Part of the reason for such a great spread may be what costs they included in their total budget.

Of 49 responses to the question "Do you have an established methodology for determining where patching is needed in your area?" 28 agencies (57.1%) said yes and 21 (42.9%) said no. In many cases, the methodology involves agency personnel knowledgeable about the roads in their area who inspect the roads and report on the need for patching; these include maintenance foremen or superintendents, pavement engineers, department patrols, and snow plow operators.

States were also asked what triggers a need for patching; the responses are shown in Figure 14. All but one agency responding (48 total) indicated that visual inspections trigger a need for patching, followed closely by public complaints (43), safety issues (42), and size of a pothole (40). Less frequent but still significant triggers included poor ride quality (28), extent of cracking and extent of scaling or spalling (27), depth of rutting (26), roughness or raveling (24), and width of joint (20). Rumble strip deterioration was noted as a trigger for patching by one state.

The most common distresses requiring patching are shown in Figure 15. Potholes are the most common distress, by far.

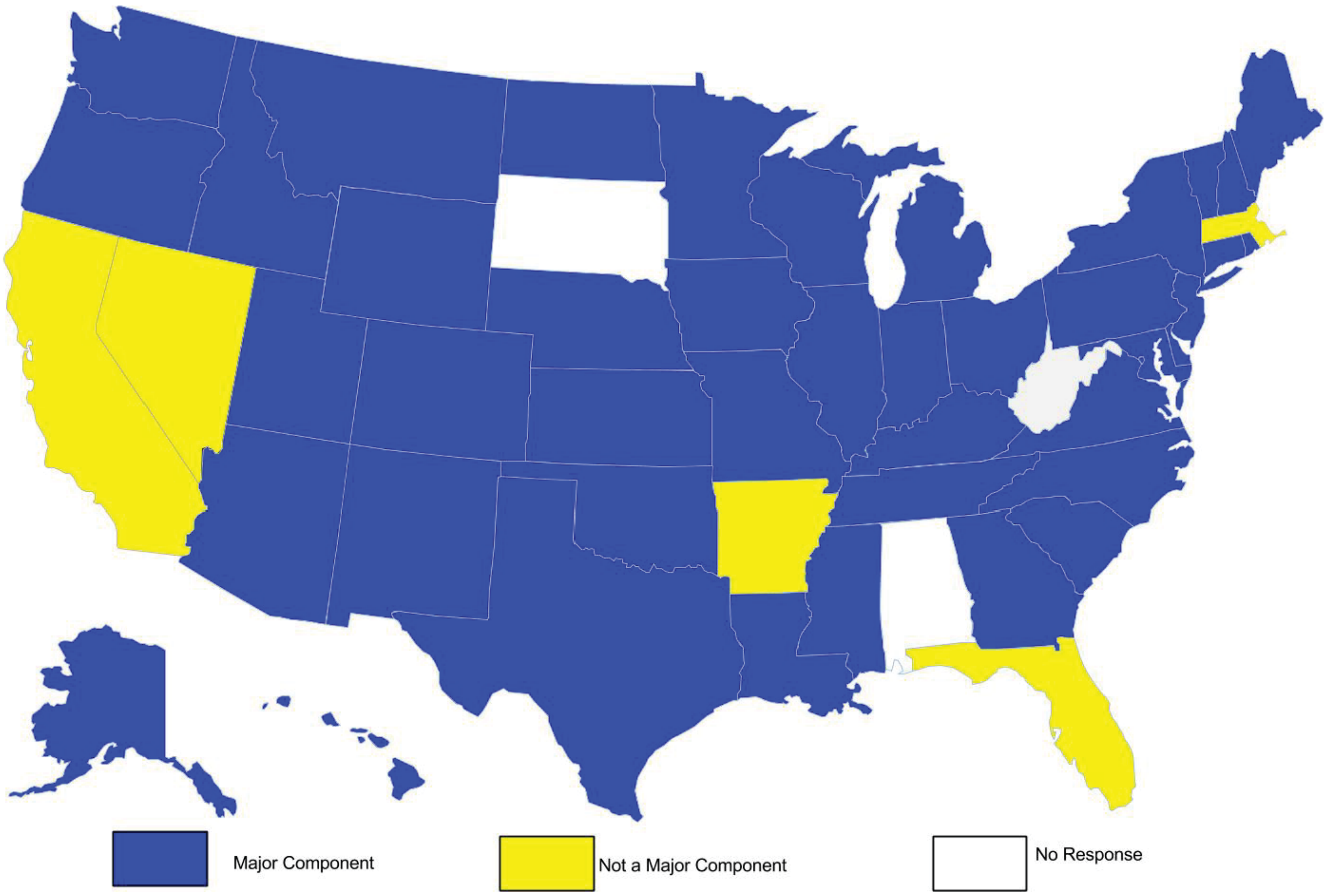



FIGURE 13 Do you consider patching a major activity? (*Source*: survey responses.)

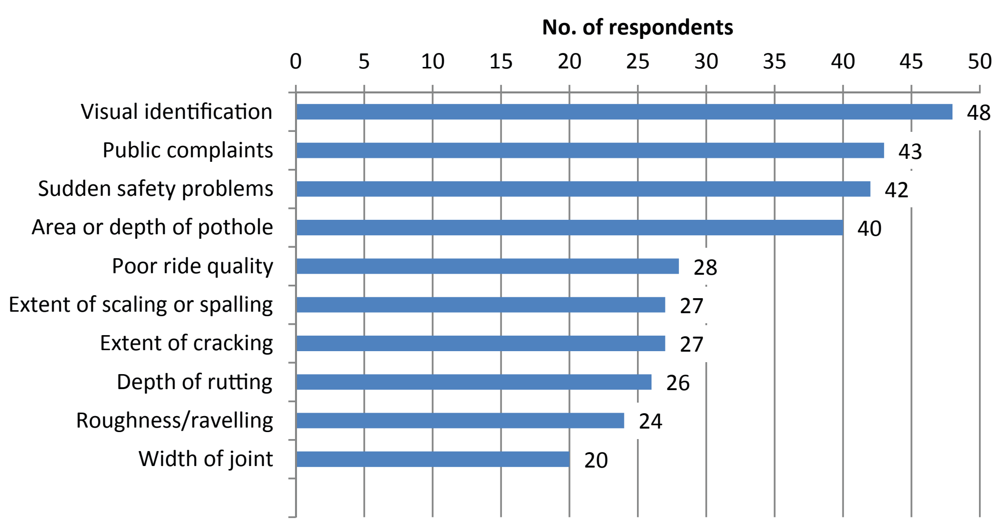



FIGURE 14 Is there a trigger that calls for patching? (*Source*: survey responses.)

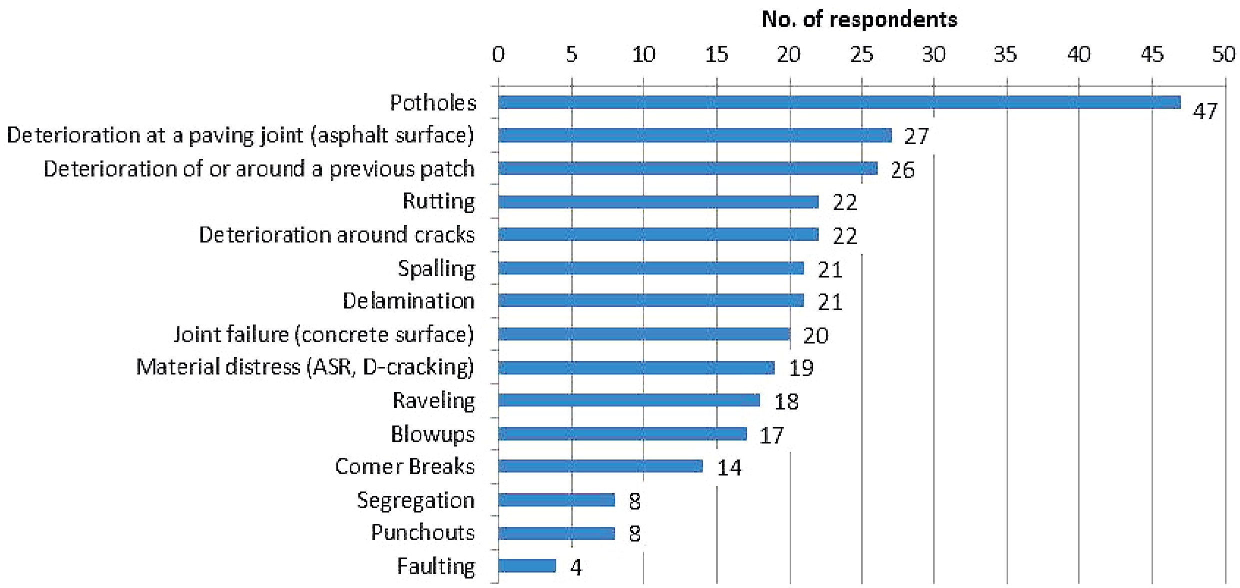



FIGURE 15 What are the most common distresses requiring patching? (*Source*: survey responses.)

Other significant distresses that are patched include deterioration at a joint in an asphalt surface and deterioration around a previous patch. Rutting, deterioration around joints on a concrete surface, spalling, delaminations, and joint failure are the next most common. In addition to the options given in the survey, states commented that alligator cracking, frost heaves, permafrost-induced heaving and subsidence, stripping around paint striping, and top-down fatigue cracking also lead to a need for patching.

The survey also asked who performs patching operations. Reactive patching is performed by state workforces in all but one of the agencies responding, as shown in Figure 16. In addition, eight states use paving contractors and four use specialty contractors for reactive patching. State workforces also do planned patching in 37 agencies, paving contractors do planned patching in 34 states, and specialty contractors in 13 states. There are a variety of approaches used to perform patching. Wisconsin reported that county highway departments do all of its maintenance; in Georgia, the state contracts with some counties to perform maintenance on state roads. Virginia and Texas report awarding large-scale maintenance contracts. In Nevada, all asphalt patching is done by state workforces and all planned concrete patching is done by contract. North Carolina is among the states that perform maintenance for the counties.

Another question on the survey asked states to estimate how much time elapses between identifying the need to patch and completing the repair; the results are shown in

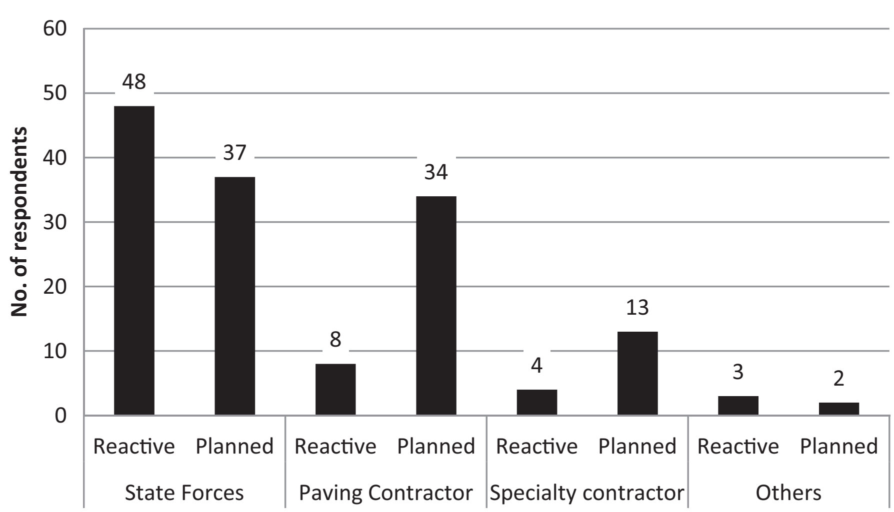



FIGURE 16 Who performs patching in your state? (*Source*: survey responses.)

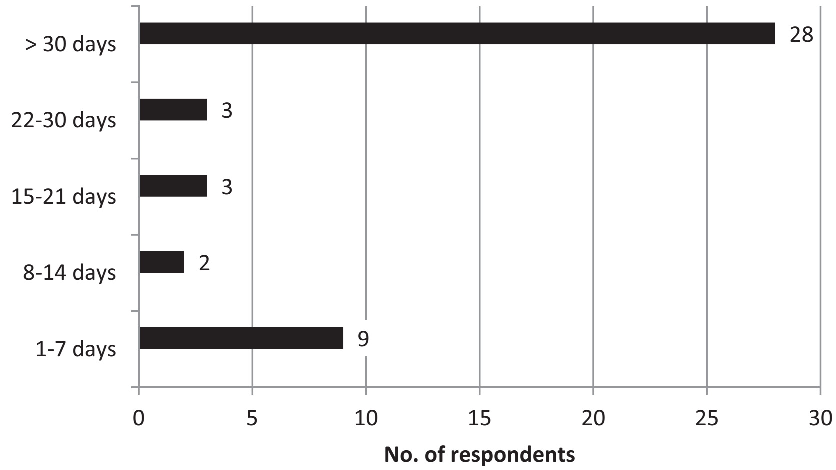



FIGURE 17 Typically, how much time elapses between becoming aware of patching need and completion of the patch? (*Source*: survey responses.)

Figure 17. Because reactive patching often addresses a suddenly occurring, potentially emergency situation, in most cases the reaction time is quite rapid. A reaction time of 1–7 days was reported by 42 of 46 respondents, 8–14 days by three, and 15–21 days by one. Conversely, planned patching is typically accomplished in more than 30 days in 28 of the 46 states reporting. Some states (17) report accomplishing this more rapidly, with responses ranging between 1–7 and 22–30 days.

To identify which states have detailed requirements for patching, the survey asked if states had or worked from plans, specifications, or guidelines for various kinds of patching, including reactive versus planned, and temporary versus permanent. The results (Figure 18) showed that these types of documents are used by 29 of 47 responding states for reactive patching and by one state for reactive patching by contract. Twenty-eight of 47 states reported using these documents for planned patching; however, 13 use them for planned patching by contract only. A total of 23 states reported using these standards for temporary patching and 32 for permanent patching. In addition, eight states use standards for permanent patching by contract only.

Along with standards for patching, the means of assessing quality are also important; therefore, states were asked if they have any QC/QA procedures for patching operations. Only 16 of 49 agencies reported having any QC/QA procedures in place for patching (Figure 19). More often than not, these QC/QA procedures apply to concrete patches and involve testing concrete strength before opening to traffic; in one state, air content and slump were also measured. Smoothness or ride quality of the patch is sometimes evaluated, as are mix design and manufacturer certifications. Use of a straight

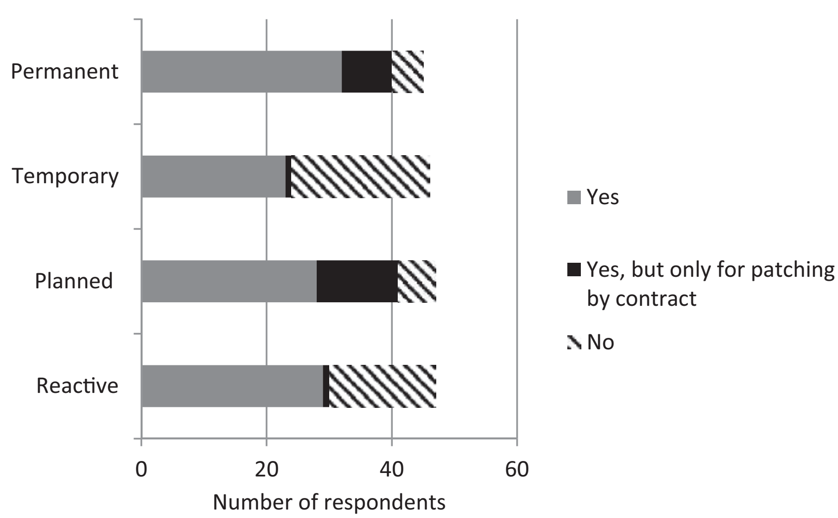



FIGURE 18 Does your organization have specifications, plans or guidelines for patching? (*Source*: survey responses.)

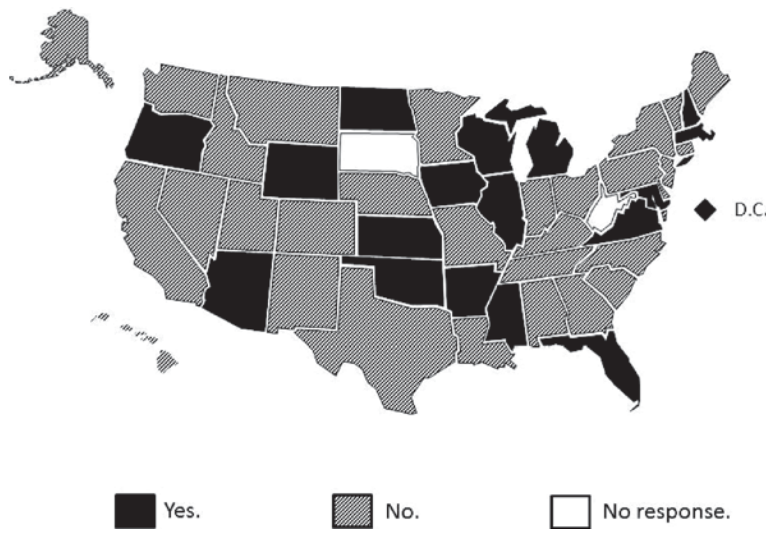



FIGURE 19 Does your organization have any QC/QA procedures at the time of patch placement? (*Source*: survey responses.)

edge to check the smoothness and flush surface of the patch was common. One state reported checking density of the patch; another requires the use of "ordinary compaction," a standard compaction process. For asphalt patches, having an approved mix design or checking gradation were also reported quality checks. Visual inspections during and after patching are also performed. Inspection and testing are sometimes more rigorous on patching by contract than in-house patching. (See chapter five for an example of a patch inspection procedure used in one state.)

States were queried to determine if they monitor the performance of patches placed in their jurisdictions. The performance of installed reactive patches is monitored routinely by 18 of 48 agencies responding and for contract work only by three additional agencies. More states monitor the performance of planned patches (24 of 49), with an additional six states monitoring planned contracted patches, leaving nearly half the states that do not monitor the performance of patches in their jurisdictions (Figure 20).

To track the performance of patches, it is necessary to know where they are; therefore, states were asked if they have an established method for tracking the location of patches. Nineteen of 49 states track the locations of reactive patches and 26 of 49 track planned patches (Figure 21). Most tracking is done by roadway segment or reference post (mile marker). Washington State is working with one of its regions to track patch locations using GPS. These locations are then stored in the pavement management system. Louisiana uses its maintenance management system to track locations; a planned upgrade will use handheld devices and GIS to record patching locations. Overall, the maturity of the location referencing varies widely from very general (i.e., districts) to locating individual potholes (i.e., GPS). The Washington State system is described in more detail in chapter five.

Another question asked if states used any form of automated equipment for placing patches (see Figure 22). Some type of automated equipment is used for installing patches by 25 of the 45 agencies responding to the question and by an additional three agencies for patching by contract only. This equipment includes predominantly spray patchers and pavers.

The safety of the workers and the traveling public is critically important; therefore, a question on the survey asked what types of traffic management procedures were used for reactive and planned patching activities. The options given included flaggers, lane closures with cones, lane closures with arrow boards, lane closures with barriers, flashing lights and arrows on trucks and equipment, and traffic signals. The responses revealed that traffic management procedures used during patching operations vary widely depending on a number of factors such as type of roadway, type of patching operation (and the time it takes to install the patch), and traffic levels. Figure 23 shows the reported types of traffic control measures used; 47 agencies reported. Nearly all use flaggers for at least some patching operations, followed closely by lane closures with cones or arrow boards. Almost all agencies also report using flashing lights and arrows on trucks and equipment. Barriers and traffic signals are used much less frequently and more often for planned patching when they are used. One state reported that barriers are used only for planned concrete pavement patching. No agencies reported patching without traffic control, even under adverse conditions when throw-and-go techniques might be used. Individual agencies recounted using other types of traffic control devices including:

- Automated assisted flagging devices,
- A pilot car,
- Work zone signing,

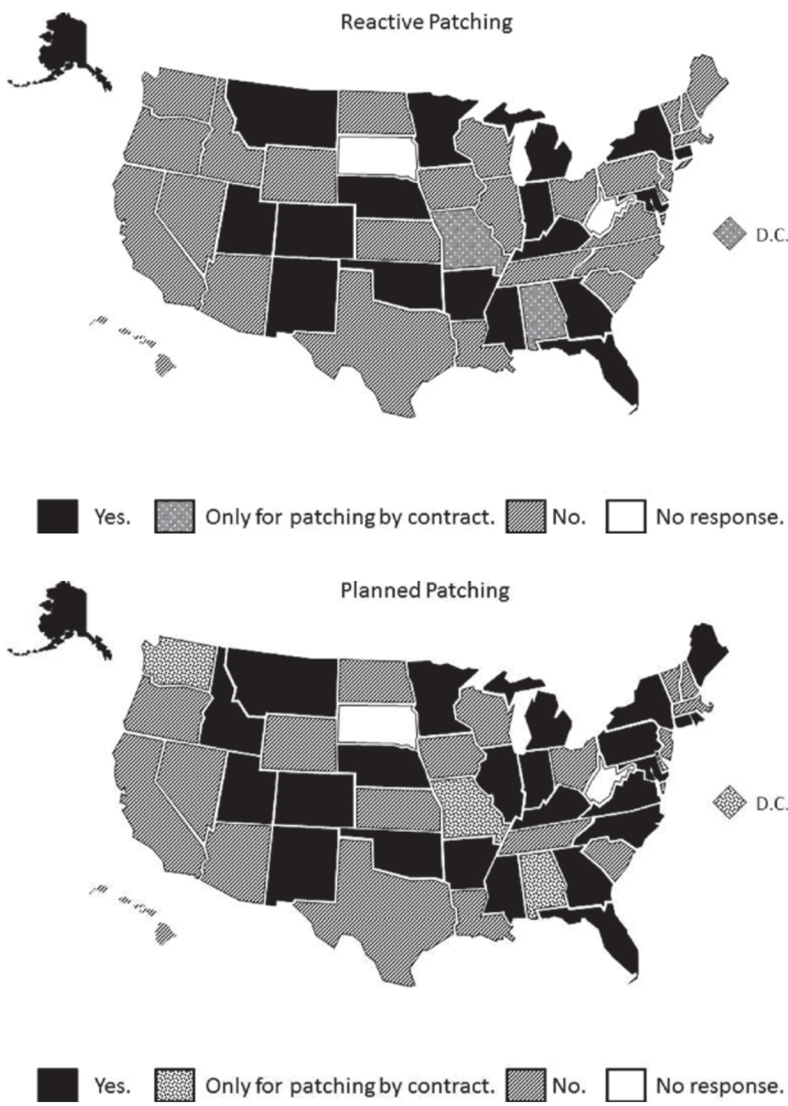
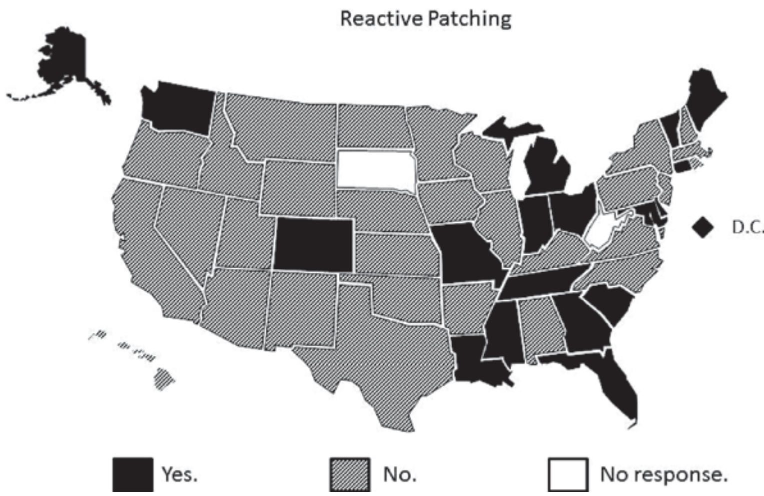



FIGURE 20 Do you monitor the performance of reactive (*upper*) or planned patches (*lower*)? (*Source*: survey responses.)



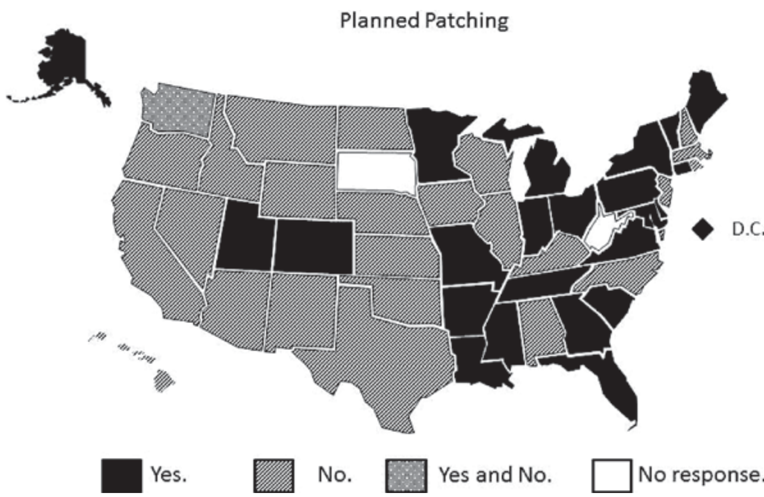




FIGURE 21 Do you have an established method to track patch locations? (*Source*: survey responses.)

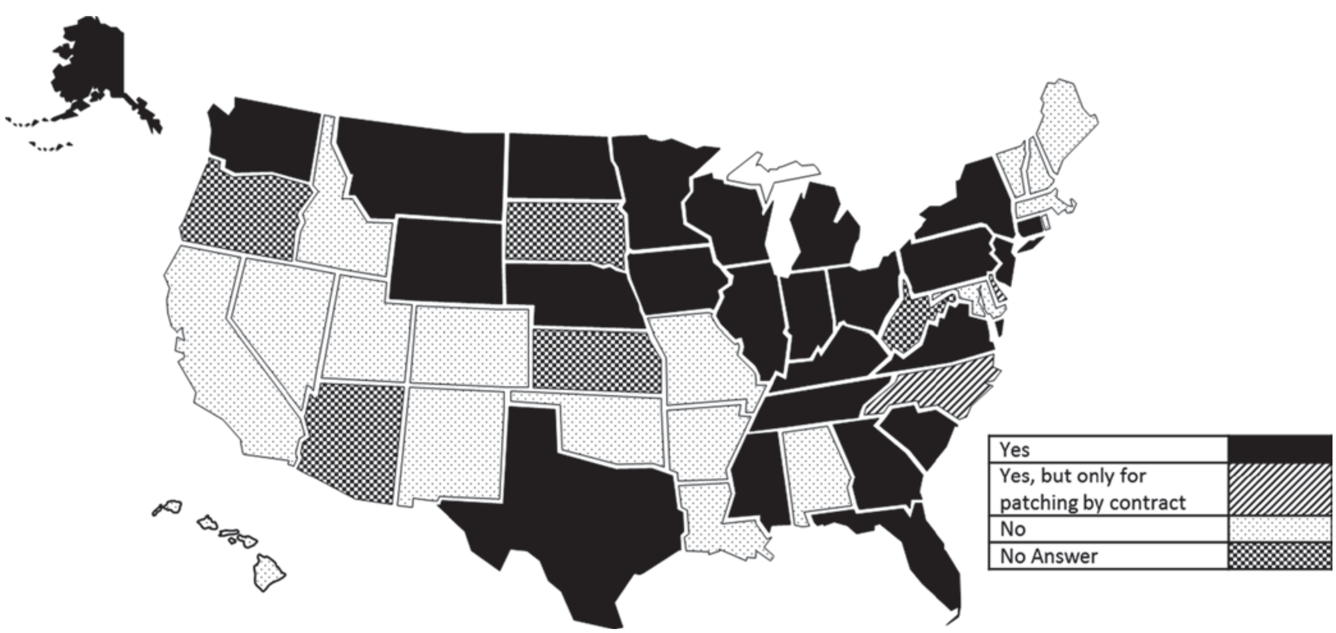



FIGURE 22 Does your organization use any form of automated equipment/machines for placing patches? (*Source*: survey responses.)

- Changeable message boards and dynamic message signs, and
- Police slowdowns for reactive patrols.

Agencies were also asked about the typical costs for patching; specifically, they were asked to report the average unit cost of patching using whatever unit of measure they apply. Many states were unable to answer the question because they do not track that data. For those states that did specify a number, there was no consistency in how that data were reported or what costs were included in the total. Some states reported material costs only; others included traffic control, and a few included labor or equipment. Because of the wide diversity of the responses, typical costs could not be derived and are not reported here. One interviewee suggested that developing a consistent reporting method and including all of the costs associated with patching would give states a better understanding of the scope of the effort and impacts of patch performance.

### SURVEY AND INTERVIEW FINDINGS REGARDING PATCHING ASPHALT PAVEMENTS

One question on the survey inquired about what materials are used by states for patching asphalt pavements. The responses, shown in Figure 24, indicate that the states were in agreement that hot mix asphalt is the preferred material for permanent patches, being used by 47 of 49 states. Generic stockpile mix is the next most common material and is used by 37 of 49 states. Currently, warm mix is seldom used; however, this situation may change in the near future as it becomes increasingly more common and accepted, pending the results of several research projects. Polymeric materials such as epoxies are rarely used (six of 49), most likely because of the relatively high costs and lack of familiarity. It has been reported that state workforces, which do most of the patching in the DOTs, are unfamiliar with the process of mixing these materials (*4*). Similarly, crumb rubber mixes are rarely used (two of 49); these would typically require special equipment for heating, which is not available to most states unless they are rented or used by specialty contractors.

A total of 27 states use spray injection patchers. In many of those states the equipment appears to be common, with multiple districts or maintenance units having their own equipment. For example, Indiana has one in each of the six districts, and there are reportedly more than 40 of the devices in Idaho (although not all at the DOT). The follow-up interviews revealed a considerable disparity in the success of spray patchers, which parallels the findings of the literature review (see "Performance" in chapter two).

Some states report using spray injection patchers very effectively. INDOT, for example, considers spray injection patching to be a nearly permanent repair, especially on concrete pavements. In Georgia, on the other hand, some districts have abandoned the use of spray patchers because of problems with the materials, equipment, and patch performance. In terms of materials, some districts had issues with obtaining the required liquid binder and clean aggregates. Traveling a long way to obtain the needed materials required extra time, labor, and expense. In another district, they believed the compaction of the aggregate into the hole was insufficient and the performance of the patch was inadequate. Problems with the equipment, including the emulsion "gumming up" the equipment and difficulties in ejecting the aggregate, were also reported.

Some states seal over the tops of patches. For example, Washington State and Nebraska place chip seals over the

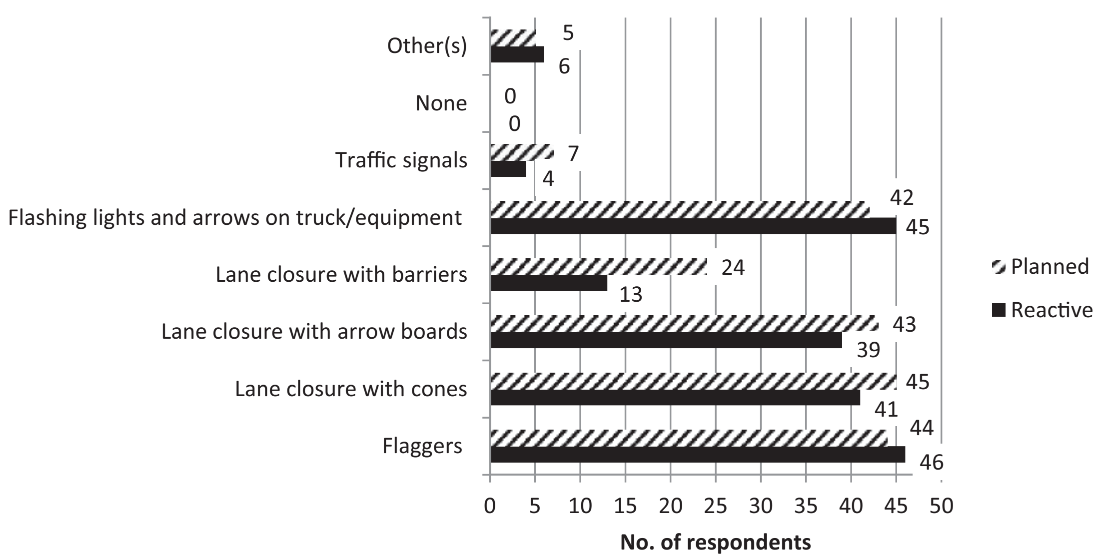



FIGURE 23 What types of traffic management procedures do you use for patching activities? (*Source*: survey responses.)

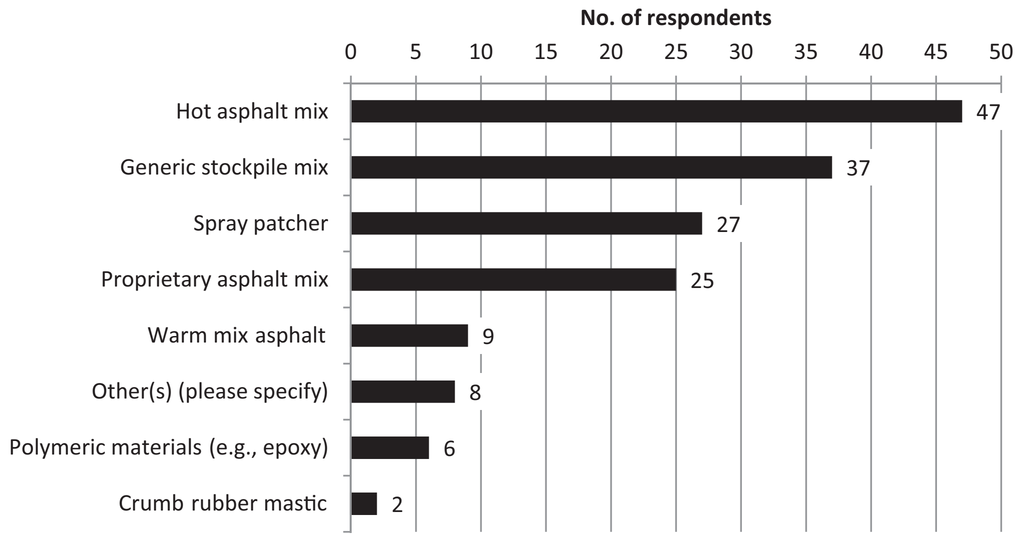



FIGURE 24 What materials are used for patching asphalt pavements in your area? (*Source*: survey responses.)

patches. Edge sealing is also recommended by some states, especially for semi-permanent patches.

The decisions over which materials to use are made based on a number of factors. The two primary factors appear to be availability and cost. The responding states also have found suitable materials that generally perform in their applications and they continue to use them. Many states maintain approved lists of materials that have passed testing or have worked in the past.

The performance of various materials varies widely. Climate obviously has an effect, with patching generally performing better in warmer, drier climates. Other factors play a significant role as well, particularly installation conditions and attention to detail. In some cases, lack of records of what materials were used in specific locations and inadequate follow-up inspections hamper judging which materials perform the most effectively.

## SURVEY AND INTERVIEW FINDINGS REGARDING PATCHING CONCRETE PAVEMENTS

States were also asked what materials are used for patching concrete pavement. As shown in Figure 25, asphalt patching material is most commonly used for patching concrete pavements as well as asphalt pavements (see Figure 24) with 41 of 49 states using it. However, many agencies consider asphalt patches on concrete to be a temporary solution until a more permanent fix can be applied. Rapid strength hydraulic cement concrete and normal hydraulic cement concrete are both used by more than half the responding states (31 and

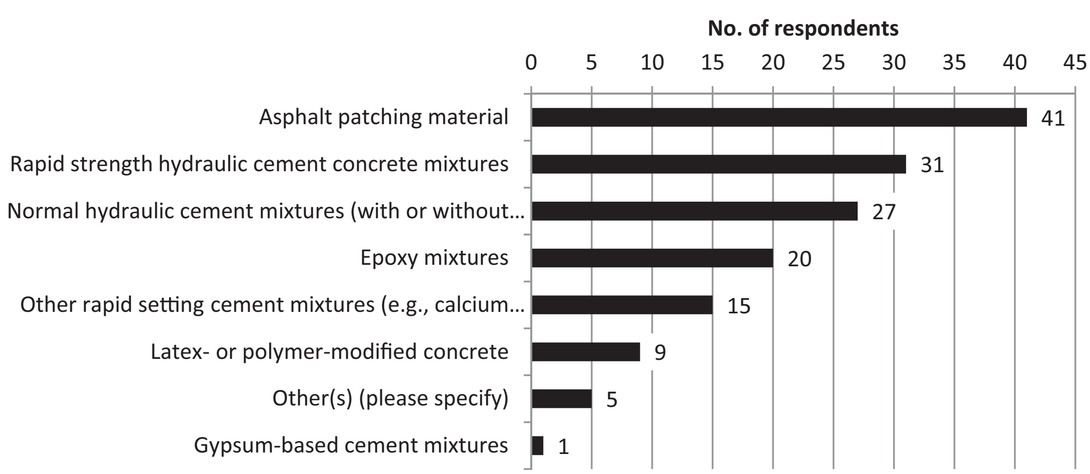



FIGURE 25 What materials are used for patching concrete pavements in your area? (*Source*: survey responses.)

27 out of 49, respectively). Epoxy mixtures are used much more often on concrete pavements than on asphalt pavements, with their use reported by 20 of 49 agencies. Next are other rapid-setting cement mixtures, such as calcium aluminate, calcium sulphate, and magnesium phosphate. Latex or polymer-modified concrete is used by nine of the 46 agencies responding. One state, however, reported that they stopped using latex modified concrete for patches because of problems with the longevity of the patch.

The use of contracts for patching concrete pavements is more common than for asphalt pavements, probably because of the skill level required to place concrete. Large patches, such as panel replacements, require specialized equipment and are therefore often done by contract.

## SUMMARY

This survey of state agencies in the United States was completed by 49 of 51 states, for a response rate of 96.1%. The responses show a significant amount of diversity in state practices, especially in terms of the management of patching programs. There is increased similarity, although still significant differences, in the materials used for patching pavements.

CHAPTER FOUR

# COMPARISON OF U.S. STATE PRACTICES WITH OTHER AGENCIES

This chapter presents the findings of surveys and communications with local agencies in the United States, as well as agencies outside the United States, relative to their pavement patching practices. The states' practices are compared with those of the local agencies and international organizations. The agencies responding to the surveys included:

- Twenty local agencies in eight U.S. states;
- Thirty-three highway authorities at the national and local levels in the United Kingdom and Ireland, plus three maintenance contractors; and
- Five Canadian agencies, including three provinces and two large cities.

For ease of comparison, the responses from the U.S. states, U.S. local agencies, and the United Kingdom and Ireland are included on the same graphs in the following section, "Patching Practices in U.S. Local Agencies." The discussion of the comparison of practices in the United Kingdom and Ireland to the U.S. state and local practices follows in "Patching Practices in the United Kingdom and Ireland." Canadian responses are not graphed since there were so few; discussion of these responses can be found in "Patching Practices in Canada."

## PATCHING PRACTICES IN U.S. LOCAL AGENCIES

As mentioned previously, a total of 20 respondents, representing local agencies in eight states, provided answers to the questionnaire. The local agency responses are summarized here and compared with the responses from the state agencies. Because of the small sample size, these results may not be representative of all local agencies.

As with the state agencies, the local agencies also believe patching is an important part of their maintenance program, with 19 of 20 respondents indicating so. As shown in Figure 26, local agencies place slightly higher importance on patching than the states (95% vs. 90%). Estimates of the percentage of the maintenance budget used for patching range from a low of 5% in Arapahoe County, Colorado (which includes parts of suburban Denver), in the dry-freeze region, to a high of 80% in the city of Akron, Ohio, an industrial city in the wet-freeze region.

A higher percentage of local agencies reported having an established methodology for determining where patching is needed; 81% of locals vs. 57% of states, as shown in Figure 27. It could be speculated that this may be, in part, the result of typically smaller networks that may allow closer monitoring of performance. Some local agencies do report patrolling their networks to identify problems.

The triggers that call for patching are fairly similar for the local and state agencies (see Figure 28). Cracking appears to be of somewhat more concern to the local agencies (71% vs. 55%). The width of joints and extent of scaling or spalling are less important to locals than states (33% and 38% for locals vs. 43% and 55% for states, respectively). This may be because greater proportions of the local networks tend to be asphalt surfaces rather than concrete.

The distress types addressed by patching are also quite similar between the local agencies and states, although again most of the concrete-related distress types (or composite pavement problems) appear less frequently for local agencies; the common distress patched include deterioration of the asphalt surface over a joint (composite pavements), spalling, joint failure, faulting, and punch-outs (see Figure 29). Fatigue cracking was cited by two agencies; thinner pavements that are more prone to fatigue cracking tend to be more frequently associated with local agencies with typically lower budgets.

A total of 14 local agencies reported reacting to sudden problems within 1 to 7 days (reactive patching); the other six did not respond. More locals reported responding to planned patches more quickly than the states, with six of 14 responding within 1 to 7 days; the comparison is shown in terms of percent of responses in Figure 30. This may be partly a question of interpreting Time Zero and partly because fewer contracts for maintenance are let by locals, meaning more of the patching is done in-house.

When patching is needed, local agencies rely on their own workforces to a greater extent than the states do. In other words, the local agencies reported using paving or specialty contractors less often than the states, as shown in Figure 31. This may be a reflection of typically smaller budgets for the local agencies.

In terms of traffic control measures, local agencies report using arrow boards, barriers, and flashing lights on equipment less often than the state agencies for both reactive and planned

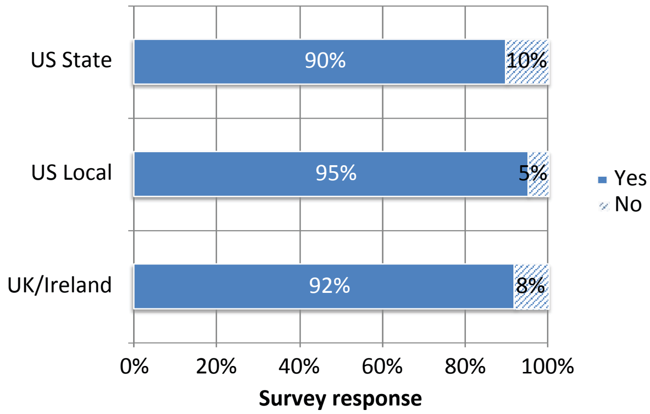



FIGURE 26  Comparison of U.S. state, local, and U.K. responses to importance of patching (*Source*: survey responses.)

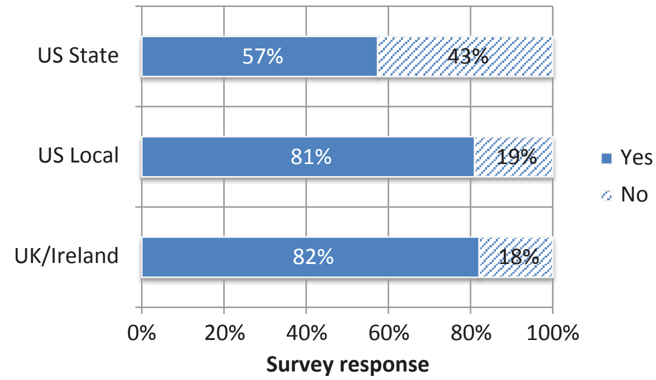



FIGURE 27  Comparison of U.S. state, local, and U.K. responses on having a method to determine need for patching (*Source*: survey responses.)

patching operations (see Figure 32). States tend to use traffic signals more often on planned patching projects. Two local agencies admitted to performing patching without traffic control in some cases; this typically involves the "throw-and-go" patching technique under adverse conditions.

In general, the states use plans, specifications, or guidelines for patching more frequently than local agencies, as shown in Figure 33. Many local agencies adopt the state requirements for patching.

Perhaps surprisingly, a higher percentage of local agencies reported having QC/QA procedures for patching, 43% versus 32% of states, as shown in Figure 34. This may be a reflection of potential bias in the pool of agencies responding, which may have been skewed toward those agencies

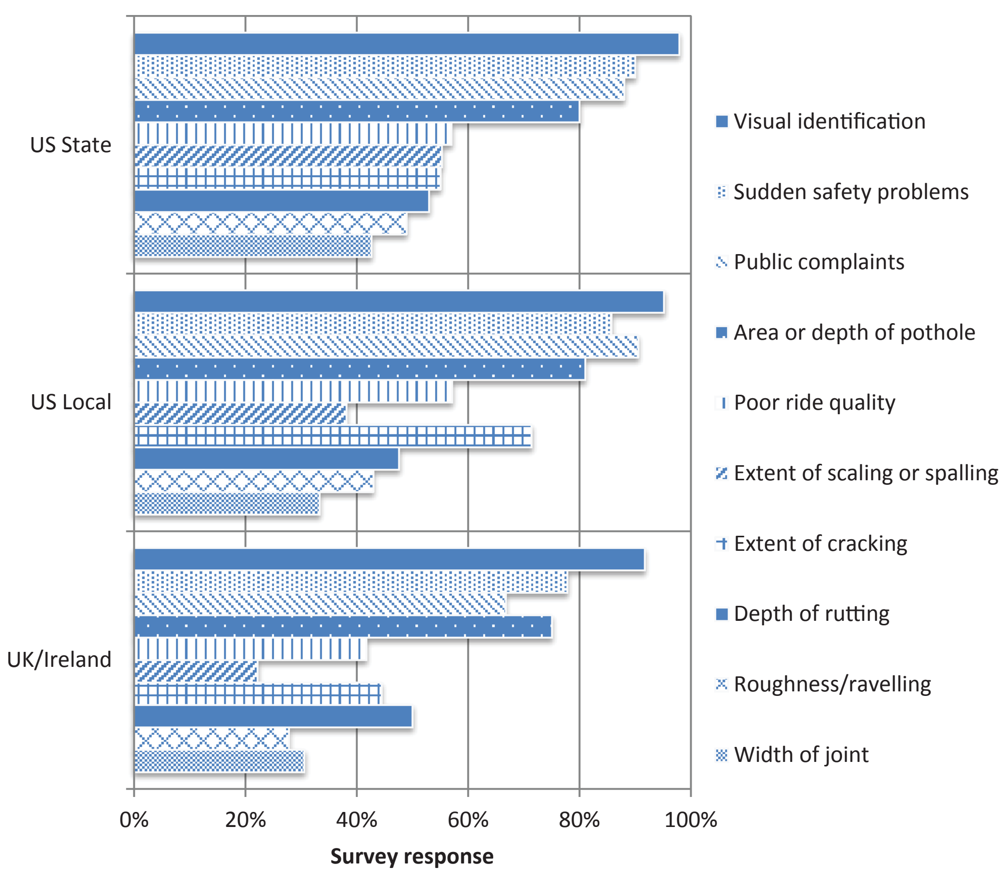



FIGURE 28  Comparison of U.S. state, local, and U.K. responses to "Is there a trigger that calls for patching?" (*Source*: survey responses.)

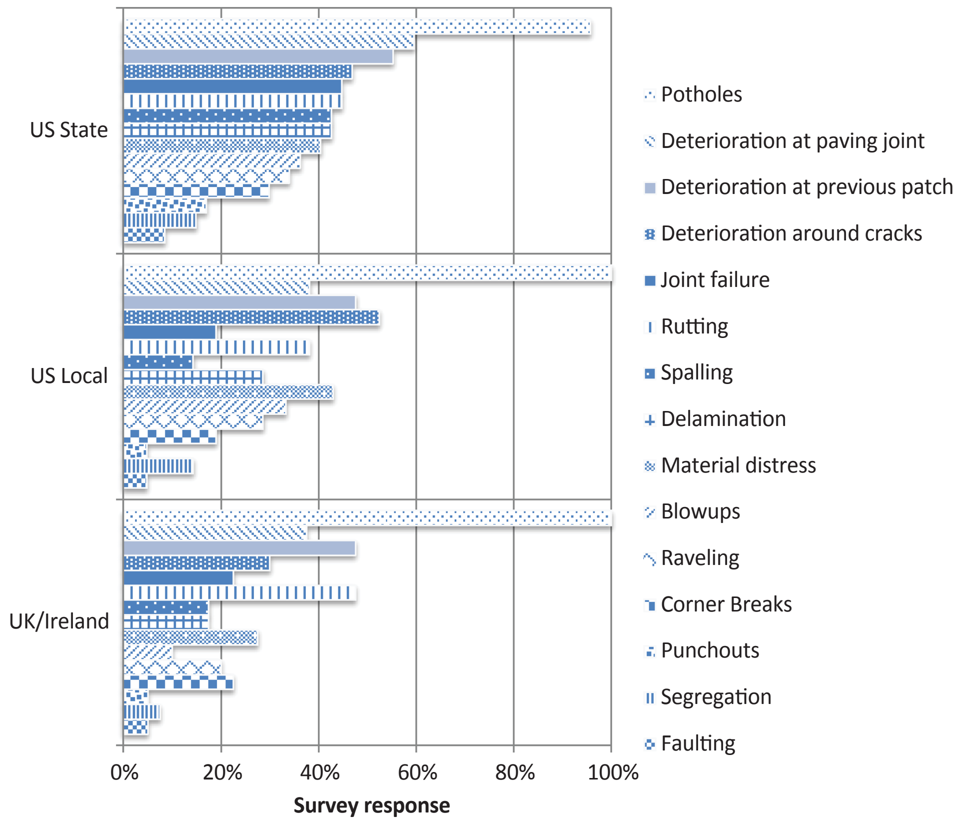



FIGURE 29 Comparison of U.S. state, local, and U.K. responses to “What distresses require patching?” (*Source*: survey responses.)

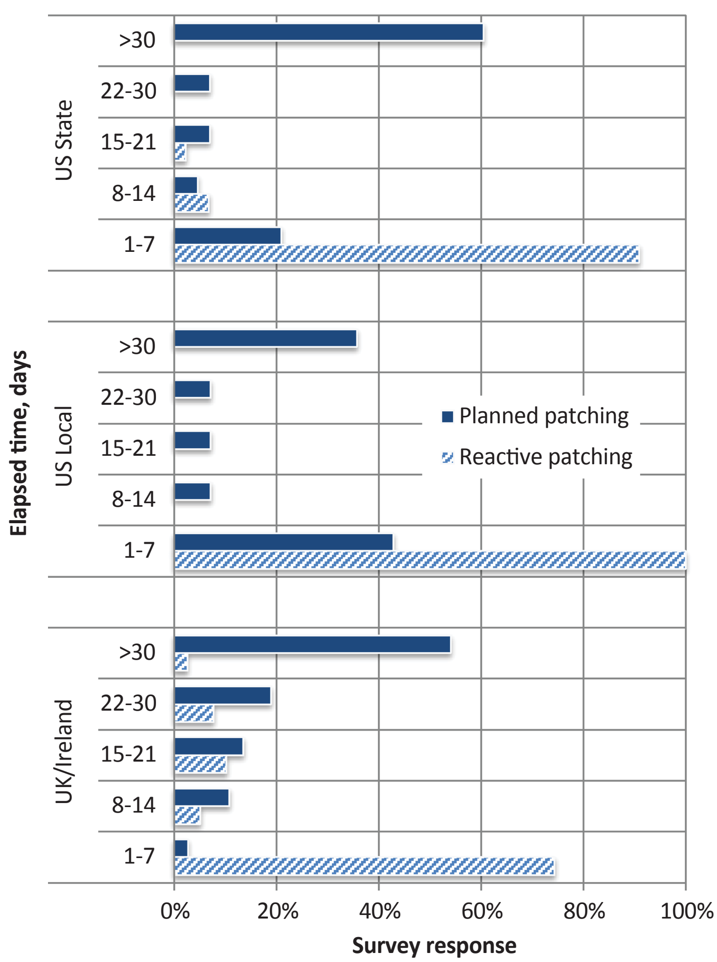



FIGURE 30 Comparison of U.S. state, local, and U.K. responses to “Typical time needed to complete patching?” (*Source*: survey responses.)

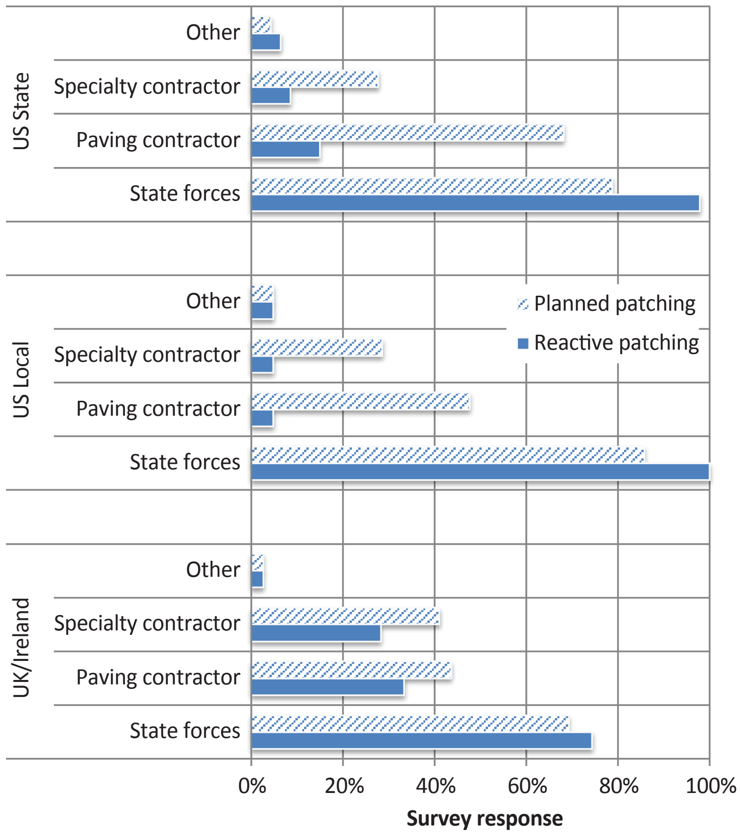



FIGURE 31 Comparison of U.S. state, local, and U.K. responses to "Who places patches?" (*Source*: survey responses.)

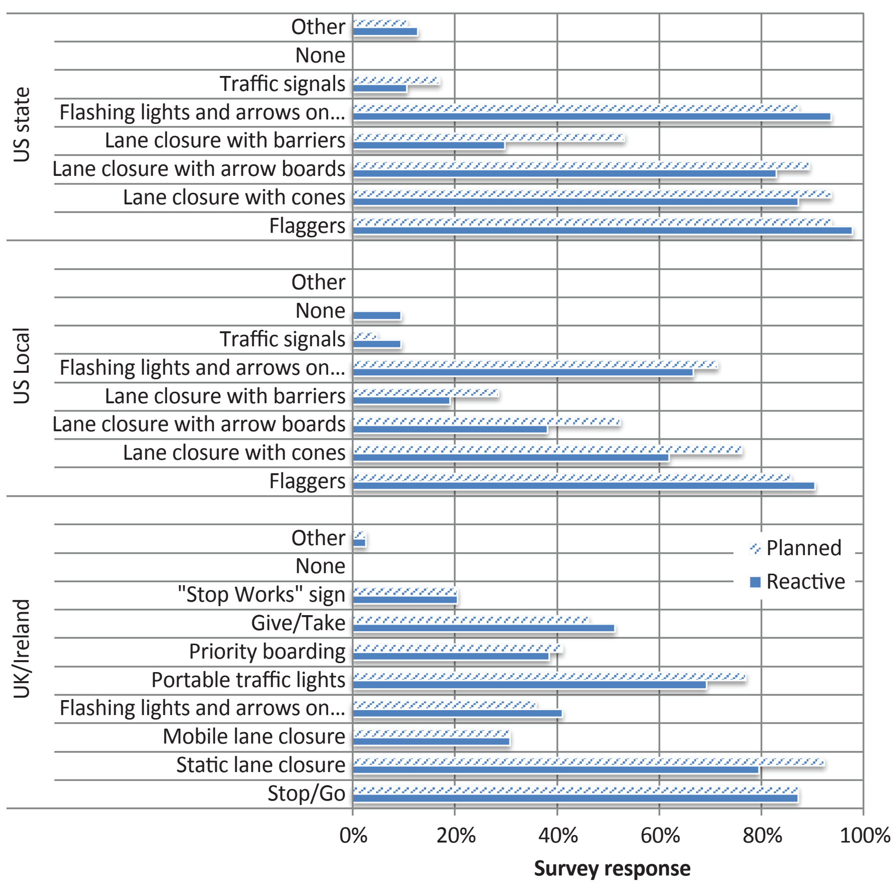



FIGURE 32 Comparison of U.S. state, local, and U.K. responses to "What traffic control measures are used?" (*Source*: survey responses.)

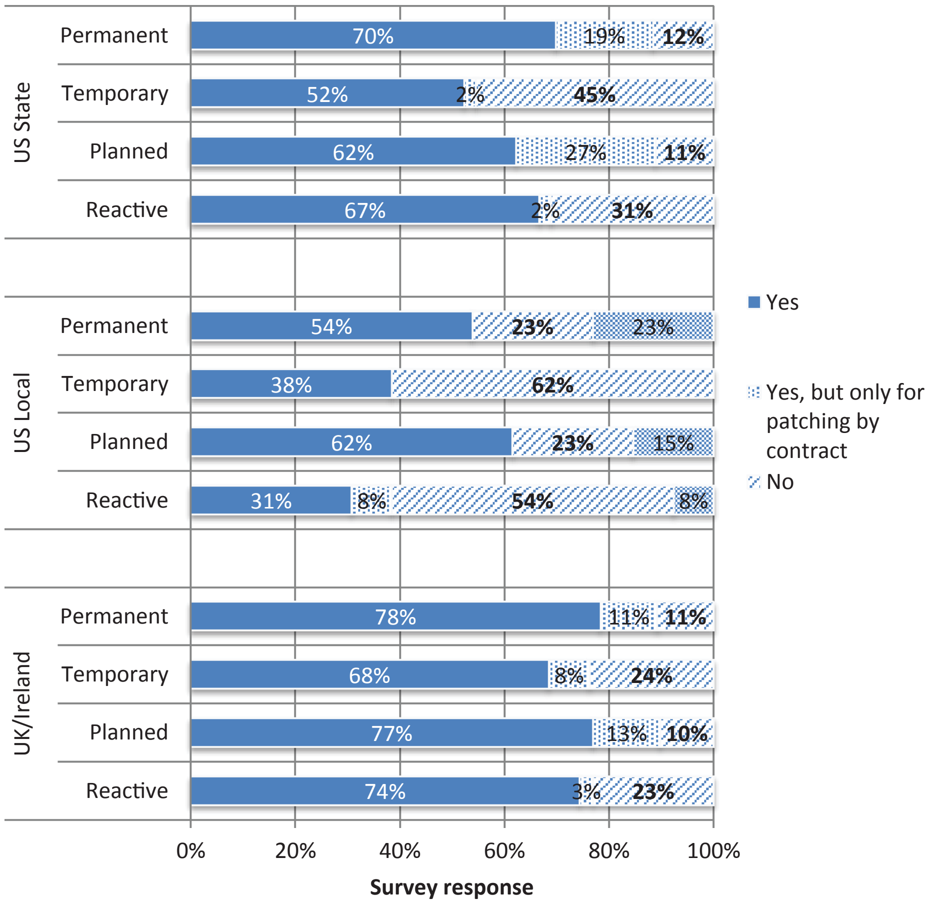



FIGURE 33 Comparison of U.S. state, local, and U.K. responses to "Do you have plans, specifications, or guidelines for patching?" (*Source*: survey responses.)

with a greater level of interest in patching or may depend on how they interpret the term QC/QA. The procedures used to assess quality are reported to include measuring density, concrete strength, survival of the patch, thickness, quality of materials, and smoothness.

A higher percentage of local agencies also reported monitoring the performance of both reactive and planned patches than the states; about 67% vs. 38% and 71% vs. 51%, respectively, as shown in Figure 35. States report tracking the location of planned patches to a greater extent than the locals do (55% vs. 38%), but the results are closer for reactive patches (40% of states and 38% of locals); see Figure 36.

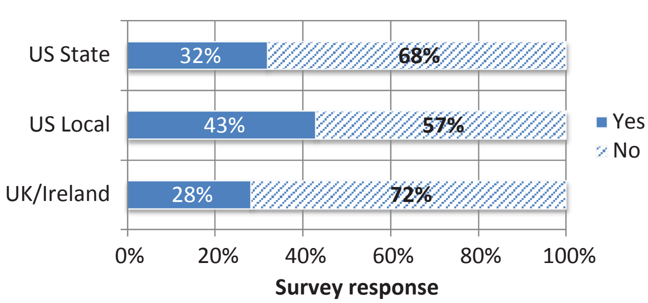



FIGURE 34 Comparison of U.S. state, local, and U.K. responses to "Do you have any QC/QA requirements at placement?" (*Source*: survey responses.)

The use of automated equipment is fairly similar, in terms of percentage of responses (see Figure 37). About 62% of the local agencies and 59% of state agencies report using automated equipment. Two local agencies (out of 20) also reported using automated equipment only on contract work; of these two agencies, both report using paving contractors for planned patching and one also uses specialty contractors. This automated equipment is usually a spray patcher. In one state, several local agencies reportedly have a specialty contractor do infrared heating patching.

Comparisons of the materials used by local and state agencies are shown in Figures 38 and 39. It can be seen from Figure 38 that a higher percentage of state agencies use generic and proprietary stockpile materials, spray injection, and polymers. The discrepancies are even greater with the materials for patching concrete pavements. The local agencies use cementitious materials much less frequently than the states (Figure 39), in large part because several of the responding local agencies reported having little to no exposed concrete surfaces in their jurisdictions.

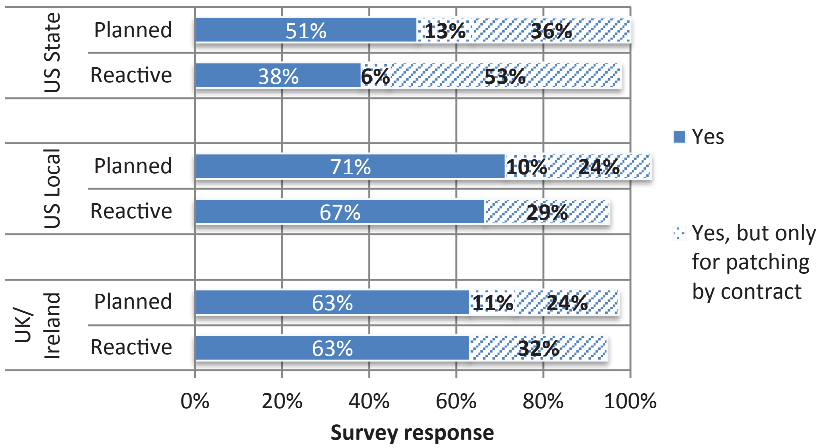



FIGURE 35 Comparison of U.S. state, local, and U.K. responses to "Do you monitor patch performance?" (*Source*: survey responses.)

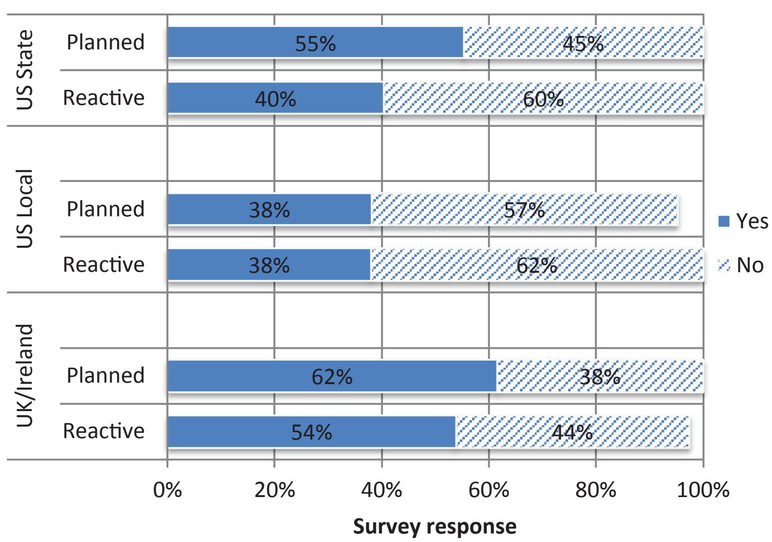



FIGURE 36 Comparison of U.S. state, local, and U.K. responses to "Do you have a method for tracking patch locations?" (*Source*: survey responses.)

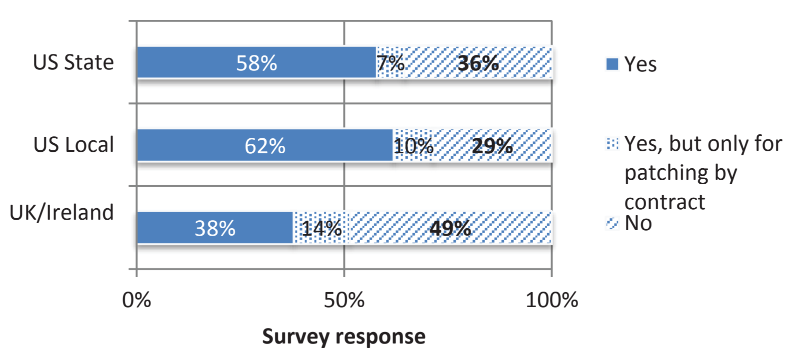



FIGURE 37 Comparison of U.S. state, local, and U.K. responses to "Do you use automated patching equipment?" (*Source*: survey responses.)

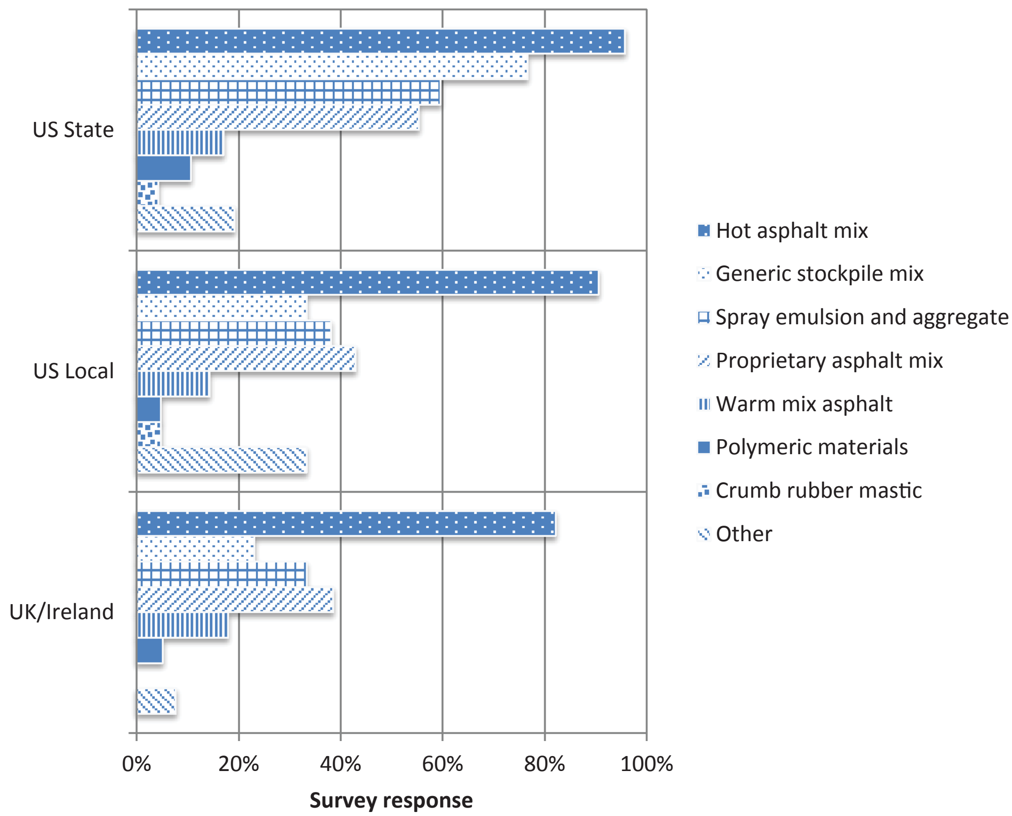



FIGURE 38 Comparison of U.S. state, local, and U.K. responses to "What materials are used to patch asphalt pavements?" (*Source*: survey responses.)

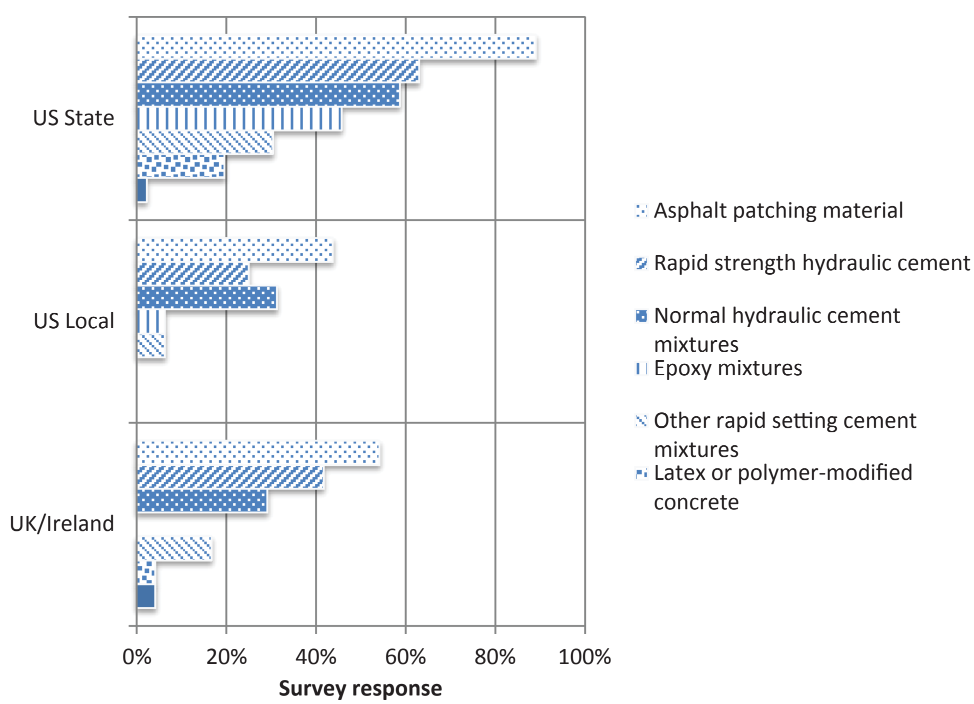



FIGURE 39 Comparison of U.S. state, local, and U.K. responses to "What materials are used to patch concrete pavements?" (*Source*: survey responses).

As there was variability between the states, there was also variability found among the local agencies responding to the survey. There were also differences between the responses from local agencies compared with the state agencies. Many of these differences could be attributed to the different scale of operations and budgets between local and state agencies. The typically smaller roadway networks for the locals allow a greater familiarity with the status and performance of the pavements. Conversely, the typically smaller budgets may limit what local agencies can do themselves and what they must contract out, if funding allows.

## PATCHING PRACTICES IN THE UNITED KINGDOM AND IRELAND

In the United Kingdom and Ireland, recent severe winter conditions have caused significant damage to the roadway networks, and roads are deteriorating more rapidly than usual (*74*). Thus the need to maintain roads is a growing concern (*75*). A version of the U.S. screening survey was distributed to organizations dealing with roadways in the United Kingdom and Ireland to assess the current practices regarding pavement patching. A total of 36 survey responses were received from these agencies, including the national Department for Regional Development in Northern Ireland, almost 30 city and county councils, and three private contractors. (The responding agencies are listed in Appendix B.) The survey findings and differences between the various road authorities are explored in more detail in Pollock (*75*).

When asked if patching is a major part of their maintenance operations, 33 of 36 responses (92%) indicated that it was, as shown in Figure 26. This response rate was similar to the U.S. state response level of 90%. One respondent who said no represented a borough council and indicated that if patching amounts to more than about 10% to 15% of an area, that agency considers resurfacing as an option; they have found that even if the patches in such an area are of high quality, the area around the patch soon deteriorates, making resurfacing a more cost-effective approach. The reported percentages of patching as a portion of the total maintenance program varied from about 8% in Scotland to nearly 50% in Northern Ireland and England, when motorways (similar to U.S. interstates) were excluded. Motorways were generally built to and are maintained at higher standards than the remainder of the roadway networks.

The Department of Transport has published patching guidelines in *Well-Maintained Highway: Code of Practice for Highway Maintenance Management* (*76*). This code recommends creating a specific inspection frequency and a severity rating system to determine and rate maintenance needs. Many of the agencies that reported having an established methodology for determining where patching is needed (82%) have based their system on these guidelines, as can be seen in Figure 27. The six agencies that did not have a method cited budgetary constraints, the relative unimportance of patching in their operations, and a limited network as the main reasons. In Northern Ireland, the road authority determines where maintenance is needed and alerts maintenance contractors to that need. Similar to the U.K./Ireland data, 81% of respondents from U.S. local agencies reported having an established methodology for determining where patching is needed. This contrasts sharply with U.S. state agencies, where only 57% of respondents reported that they have established methods.

As in the United States, visual identification is the most common trigger for patching, as shown in Figure 28. The advantages of this method are that it requires no equipment and only requires one person to assess the need (*75*). Safety was the second most common trigger, again similar to the United States. In contrast, public complaints in the United Kingdom and Ireland were notably lower than the United States, possibly indicting less promotion or awareness of related communications channels between the public and road owner. The most notable contrast relative to the United States was the low occurrence of scaling, spalling, or cracking as a trigger for patching. This difference most likely reflects the limited quantity of concrete pavements in the United Kingdom and Ireland.

The distress types addressed by patching are also similar in the United States and U.K./Ireland (see Figure 29). Potholes are the most common distress that is patched. The least common distresses were punch-outs, faulting, and blowups—again because of the limited extent of concrete pavements in the area (about 5% of the network in the United Kingdom).

In terms of the amount of time elapsing between patching awareness or planning and actual completion, the U.K./Ireland trends again closely followed those in the United States (see Figure 30). The majority of respondents (74%) reported reactive patching to be completed within 1 to 7 days. Notably, some respondents reported completion times for reactive patches of 15 to 21, 22 to 30, and >30 days (10%, 8%, and 3% of respondents, respectively). This contrasts with U.S. findings where all local agencies reported 1 to 7 days for patching and no state agencies reported delays greater than 15 to 21 days. This may reflect smaller available budgets, networks, and workforces. With regard to planned patching, the U.K./Ireland data contrasts with the U.S. findings to some degree. While relatively high percentages of U.S. local and state agencies reported patching being undertaken within 1 to 14 days (50% and 26%, respectively), the corresponding value for the U.K./Ireland was only 14%. Similar to the United States, a large proportion of respondents (55%) indicated planned patching in the U.K./Ireland required time periods of >30 days.

The use of paving and specialty contractors to perform reactive and planned patching is more prevalent in the United Kingdom and Ireland than in the United States, as shown in Figure 31. Only about 72% of the responses indicated that patching is performed by the road authorities themselves in the U.K./Ireland. This is compared with 88% and 92% of responses for U.S. state and local agencies, respectively. Of the remainder, the use of paving and specialty contractors appears to be roughly equal (35% and 38% of responses, respectively). One agency commented that its small roadway network did not justify investing in a crew and equipment to perform patching. In other cases, specialty contractors were used for specific materials and skilled contractors used where high-quality patching is needed, such as on motorways.

The terminology and practices used for traffic control in the United Kingdom and Ireland differ from those in the United States, as shown in Figure 32. This is one of the survey questions that required the most “translation” from U.S. terminology. One conclusion that can be drawn from this figure is that the use of traffic signals is much more prevalent in the U.K. and Ireland than in the United States; portable traffic lights are used in more than 70% of the organizations reporting.

Figure 33 shows that the agencies in the U.K. and Ireland make more use of specifications, plans, or guidelines than the states of local agencies in the United States for both reactive and planned patching as well as temporary and permanent.

The majority of the U.K./Ireland respondents (72%) reported that they do not implement any QC/QA procedures at the time of placement (see Figure 34), although they do check the material quality before placement. A supplier accreditation system that helps to monitor material quality is reportedly used in some cases. For those agencies that do have some form of QC/QA at placement, the parameters evaluated include strength, smoothness, depth, and density (voids). Interestingly, it was noted that most of the QC/QA testing occurs in the regions with smaller network extents.

For both planned and reactive patches in the United Kingdom and Ireland, 63% of respondents reported monitoring installed patch performance as a standard activity (see Figure 35). This compares closely with U.S. local agency feedback, where 67% and 71% of respondents reported monitoring for reactive and planned patches, respectively. For U.S. state agencies, however, performance monitoring appears to be less frequent, with only 38% and 51% of respondents reporting its use for reactive and planned patches, respectively.

In terms of tracking patches, 54% and 62% of U.K./Ireland respondents reported the operation as standard for reactive and planned patches, respectively (see Figure 36). This was slightly higher than for the United States, with corresponding values of 40% and 55% for U.S. state agencies and 38% for U.S. local agencies. In the United Kingdom and Ireland, a contractor reported the use of a laptop tracking system with GPS. In addition to the specific location, the patch size, date, and material are also tracked. Another maintenance contractor uses a similar system based on tracking the location of their equipment.

Automated equipment is used by about half of the respondents, similar to the use in the United States (see Figure 37). Spray injection equipment and infrared heaters are used in some jurisdictions. A maintenance contractor reported using planers and other automated equipment to increase production. One reason cited for not using automated equipment is that it is not cost-effective to mobilize the equipment for isolated repairs.

As in the United States, the reported costs vary widely depending on a number of factors, which makes it hard to draw any valid comparisons.

In terms of materials typically used for patching asphalt pavements in the United Kingdom and Ireland, as shown in Figure 38, the trend noted was very similar to that for U.S. agencies, with hot asphalt mix being most commonly used (82%). As with the U.S. local agency data, proprietary asphalt mixes and spray emulsion and aggregate were the next most commonly reported options (39% and 33%, respectively). Polymeric materials are rarely used and, unlike the United States, the use of crumb rubber mastic was not reported by any of the U.K./Ireland agencies.

For concrete pavements, as shown in Figure 39, similar trends were again noted, with asphalt and rapid strength hydraulic cements being the first and second most reported materials (54% and 42%, respectively). Clearly, with these options, the speed with which the roadway can be reopened to traffic is the primary benefit. Calcium sulfate and epoxy were not used.

In general, it appears the experiences of national and local roadway authorities in the United Kingdom and Ireland are quite similar to those of the state and local agencies in the United States. There are some differences, especially regarding the use of contractors for performing patching operations; however, in general similar materials, methods, and management techniques are used.

## PATCHING PRACTICES IN CANADA

Only five responses were received from Canadian provinces and cities; therefore, this small sample size may not be representative of the country as a whole. Because of the small size of this sample, the results are summarized in this section but not graphed because they could be misleading.

- As in the United States, the responding Canadian agencies generally believe patching is a major activity within their maintenance programs, with four of five reporting it as important.
- The same triggers are important in Canada as in the United States. The most commonly cited triggers include visual identification and safety issues (four of five responses); public complaints, size of the distressed area, rut depth, and poor ride (each three of five).

- As in the United States, there was little consistency in how the costs of patching were tracked and reported.
- The same distresses were deemed suitable for repair by patching as in the United States. The most common distresses were potholes (four); and rutting, raveling, and crack deterioration (three each). Concrete pavement distresses such as scaling and spalling were less frequently mentioned by the responding agencies, which generally reported having relatively little exposed concrete pavement. Agencies also reported patching dips over culverts and permafrost.
- The time to respond to a patching need also showed trends similar to those in the United States. Reactive patching is typically addressed within 1 to 7 or 8 to 14 days. Planned patching takes longer, on average more than 30 days.
- Two of the responding agencies reported having specifications for reactive patching, and four of five have them for planned patching.
- Just two of the five responding agencies have QC/QA procedures for patching.
- The materials used for patching by the responding agencies were somewhat more limited than that revealed in the U.S. surveys of state and local agencies. This is likely because of the small sample size. Patches on asphalt pavements are reportedly done using hot mix asphalt, proprietary asphalt mixes, and spray patching (four of five). One agency reported using generic stockpile mix. For concrete pavements, asphalt mixes are used by four of five agencies and rapid-set hydraulic cement by one. Again, these agencies have relatively little exposed concrete.
- Automated equipment for patching is used by all five agencies. Spray injection patchers are the most common automated equipment in use.
- Patching is performed by both agency and contract personnel.
- Similar traffic control measures are used.
- Two of the five agencies reported monitoring of performance and two have a method to track patch locations; however, they are not the same two. Only one agency reported having a method to track locations and monitor performance.
- One of the needs cited by the responding agencies was for training of maintenance personnel.

CHAPTER FIVE

# CASE EXAMPLES

This chapter presents case examples of agencies that either illustrate common most effective practices or are trying new approaches. These case examples were identified through the survey responses and explored through follow-up interviews, e-mails, and a literature review.

### MAINTENANCE QUALITY ASSURANCE PROCESS—INDIANA DEPARTMENT OF TRANSPORTATION

Although many states have management programs that include pavement patching, the one used by INDOT requires post-installation inspections by trained rating panels.

INDOT's Maintenance Quality Assurance Process (*77*) covers nine maintenance activities that are considered to have a major impact on roadway performance. Two of these activities are shallow patching and deep patching, which are performed on both asphalt and concrete pavements. These activities are reported by the maintenance units that perform them, and QA inspections are performed by teams of trained raters—one team in the northern part of the state and another in the south. Annual reports are prepared that compare the performance of the maintenance activities across the state. These inspections and the reports are used to revise the standards and to improve the patching practices. In some cases, they have been used to explore why patching performs better in some places than in others; so far, this has mainly come down to techniques rather than materials.

The need to patch is determined by field inspection or public complaint. Each of the state's six districts has a pavement engineer who is responsible for all pavement-related activities in the district. The pavement engineer is familiar with the roads in the district and determines where work is needed. A maintenance subdistrict foreman may also identify the need for attention. Some maintenance contracts are let; however, the majority of the work is done with state workforces, especially on asphalt surfaces.

As defined by INDOT, shallow patching is "minor patching of small areas of bituminous roadway or paved shoulder with hot or cold bituminous mixtures with hand tools to correct potholes, edge failures, and other . . . hazards" (*77*). This work is performed by the maintenance units. Holes that are more than 1 in. deep and 12 in. in diameter are supposed to be repaired as soon as possible. Smaller holes do not require immediate attention but must be filled by November 1 to prevent further damage. The standards suggest that if there are many holes in an area, there may be a larger problem that cannot be addressed simply by patching.

Deep patching is more extensive patching to repair base failures, blowups, or settlements, which can occur on concrete or asphalt pavements and paved shoulders. Deep patching requires the removal of the pavement full depth. The district pavement engineer advises if a deep patch is appropriate and makes recommendations on the type of repair. The equipment requirements are more extensive than for shallow patching and include saws, jackhammers, and backhoes. As with shallow patching, the standards include details on preparations, scheduling, traffic control, and materials.

Each district has at least one spray patcher, and one district owns a paver; the paver is lent out to other districts or those districts rent equipment when needed. The district pavement engineer decides when to use the paver instead of manual patching. There are also asphalt storage trailers (hot boxes) in each district. Small rollers or vibratory plates are used for compaction on semi-permanent patches; truck tires are typically used for reactive patching (the throw-and-roll technique). Traffic control is as outlined in the department's *Work Zone Traffic Manual* (*78*).

The performance standards include details on the type of patch, surface preparation, scheduling, traffic control, type of material to use, typical crew sizes, and more. The throw-and-roll technique is recommended for winter and early spring repairs. Vibratory plates or rollers are used to compact semi-permanent patches.

Cold mix (generic or proprietary) is used as a temporary repair when needed; this is typically used for cold weather repairs when the asphalt plants are shut down. Proprietary stockpile mix is not commonly used because of difficulties in bidding out proprietary materials; in general, the state strongly prefers non-proprietary materials. The choice of material to use for patching concrete pavements also depends on the time of year, location, type of roadway, and how long a lane can be closed. An approved list of materials is maintained.

If a temporary patch is placed, it is scheduled for replacement with hot mix as a permanent patch within months after the plants reopen. Work plans are made for each fiscal year that lay out the work to be performed month by month. Temporary patches on both types of pavements are expected to last 3 to 6 months; permanent patches should last as long as the surrounding pavement. INDOT has found that spray-injected patches can perform as permanent patches if properly installed.

For both shallow and deep patching, the locations are tracked by roadway segment. A planned upgrade will tie this to reference posts; however, this will require changing the maintenance management software. The work management system tracks activities to record how much work of various types is done and where it is performed.

Follow-up inspections are performed by the rating teams. Shallow patching is inspected between 30 and 45 days after completion. Deep patching is inspected between 30 and 45 days after completion and again after one year. Not every roadway is inspected; however, one road in each maintenance subdistrict is inspected each year. Rating forms assign points for shallow patching based on how many holes were patched, are flush with the surrounding pavement, are compacted, have loose material present, and exhibit tracking. Deep patches are scored based on whether the patches are square with the pavement, cover the distressed area, are flush, and are compacted. In addition, for patches greater than 100 feet in length the pavement markings must be reestablished to get maximum points. The inspection also looks for evidence of poor drainage.

This program has been in use for many years and is performing well. It provides needed information to revise practices to get the most effective performance from these maintenance activities.

### TOOLS FOR TRACKING PATCHING—WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

GPS and GIS systems are increasingly being used in everyday activities, and advancements in technology now make it feasible to use these tools for even more undertakings. Several states, including Arkansas, Louisiana, and Maryland, are exploring the possibility of using GPS and/or GIS to track maintenance events or are planning to incorporate the technology in their programs in the near future. Washington State has already begun implementation of an internally developed system that uses GPS to track locations that can be tied to their strong GIS program.

Washington's Highway Activity Tracking System is used to track a variety of maintenance activities, including patching (*79*). The system currently allows agency personnel to input the results of inspections to identify maintenance needs and to log the repairs. The needs and repairs can be linked in the system so that tracking the responses to patching needs can be performed. Handheld GPS units are being implemented to accurately pinpoint where the repairs are needed and performed. The department believes recording an accurate location is the key to enabling meaningful analysis of the success of the maintenance.

Information recorded includes the reason for the repair, type of repair, and location including which lane (or shoulder) is patched. The system is not currently used to track the patching material used; however, this is a planned future enhancement.

The integration of GPS in the system is described as "a work in progress"; however, it is available statewide and is being used often in some regions. There is coordination and training provided by the headquarters, and training has been performed on a regional basis. The future of the system is promising and its use is expected to increase as more regions receive the training and become familiar with the capabilities of the system.

### PROCESS FOR ADDRESSING POTHOLES—MARION COUNTY, OREGON

Marion County, Oregon, the county surrounding the state capital of Salem, is an example of a local agency with established pavement patching and other maintenance programs (*80*). The Marion County Public Works (MCPW) department has written guidelines for pothole patching that include reporting potholes and setting priorities for patching. They describe a process for addressing potholes termed "The Four R's: Response, Rating, Reporting and Repair."

The *response* is an alert that a pothole has been detected. If the alert comes from a citizen or another agency, such as law enforcement, the MCPW dispatcher collects information about the location of the pothole and records it in the dispatch log, assigning an "event number." Trained personnel from the department will then visit the site and assess the severity of the pothole and the need for traffic control when making the repair. If the alert comes from MCPW staff, no visit to the site is needed as the staff member can provide the needed location, severity, and traffic control information to the dispatcher. Traffic control may require flaggers, lane closures with cones or arrows, and flashing lights on equipment. Barriers are sometimes used for longer lane closures by contractors for planned patching.

The *rating* is performed by MCPW personnel according to a chart summarizing the Pothole Severity Criteria Matrix Guidelines (*80*). The guidelines rate the severity of distresses on paved roadways, shoulders, and gravel roads. On paved surfaces, the severity is rated based on size of distress (width, length, and depth); roadway information, including classification, speed, and available driver response time; and location, in wheelpaths, in travel lanes, or anywhere on the pavement. Photographic examples are provided to assist the raters in assessing severity. High severity potholes are "large enough to do significant damage to tires, rims, suspension or axles"; the guidelines call for repairing these potholes as soon as possible. Typically, the department reports, emergency patches are placed within a day. Medium severity patches have the potential to cause tire or rim damage; the guidelines suggest these be repaired within three business days, weather permitting. Low severity potholes will probably not cause damage to vehicles and are scheduled for repair when routine patching is performed.

*Reporting* is done after the pothole severity is rated; this step involves feedback to the dispatcher with the location (by street, address, or mile post; nearest cross street; and/or lane), pothole severity, and need for traffic control.

*Repairs* are scheduled based on the severity rating, as described earlier. The materials used include bagged cold mix for temporary patches and cold mix placed in a heated enclosed truck bed or a "hot-patch truck." (The county has no concrete surfaced roadways.) The hot-patch truck allows for essentially permanent repairs to be made. The dispatcher is informed of repairs after they have been completed and records them in a log. This also allows for monitoring the quality of the patching and materials, since the repair is well-documented.

Patching is a major activity for this county, and agency personnel perform patching on an almost daily basis. Staff not only places patches on the county network, but also performs patching for other jurisdictions. Paving and specialty contractors are used on occasion.

Although this county has an established program for managing pothole patching they still see room for improvement. They specifically cite needs for more information on and understanding of the performance of different patching materials, development of new materials, development of new equipment, and the use of bonding agents. They report that the greatest needs are for better tack application and tools for patching.

Cornell Local Roads Program

NEW YORK LTAP CENTER

### EXAMPLE OF A PATCHING TRAINING PROGRAM—CORNELL LOCAL ROADS PROGRAM, NEW YORK

The Cornell Local Roads Program in New York has provided training on pavement maintenance since 1996. That training has continued and been upgraded over the years. The latest version of the workshop was first offered in 2005 in response to issues in the state regarding selection of the right maintenance strategy for a given situation (*81*).

The focus of the workshop is on understanding the causes of distress so that the proper repair technique can be selected. The course covers repair of paved and, to a lesser extent, unpaved roads and a variety of repair techniques, with an emphasis on the most common treatments, including patching, crack sealing, and chip seals.

To foster deeper understanding of the right repair technique to use in different situations, the course starts out explaining how roads carry loads and what causes them to fail. Classroom demonstrations explain fatigue, and discussions describe other failure mechanisms and contributing factors. The causes of a failure may arise from design, construction, materials, or maintenance. The types of distress and what causes them are also presented.

Once failure has begun, the choice of what to do about it ranges from doing nothing to total reconstruction, with a number of maintenance options in between. The types of maintenance activities are outlined in Table 9.

Demand maintenance is done in response to a hazard or complaint, referred to in this synthesis as reactive patching. Pothole repair is a typical example of demand maintenance. A semi-permanent patch is considered corrective maintenance because it is planned to correct a failure after it has occurred. The appropriate times in a pavement's service life at which to apply these different types of maintenance are discussed in the course.

One chapter in the pavement maintenance manual is devoted to patching, including the reasons to patch and types of patches (semi-permanent, spray patching, and demand

TABLE 9
TYPES OF MAINTENANCE ACTIVITIES

| Type of Maintenance | Planned? | Performed Before Deterioration? | Extends Pavement Life? |
|---|---|---|---|
| Demand | No | No | Not necessarily |
| Routine | Yes | Not necessarily | Sometimes |
| Preventative | Yes | Yes | Yes |
| Corrective | Generally | No | Yes |

*Source*: Orr (*81*).

patching with cold mix). Step-by-step instructions on best practices for each of these types of patches are provided. Lastly, cost-effectiveness of the various types of patching is discussed. Table 10 summarizes the costs of different demand patching materials and procedures.

The point being made is that even with higher costs for labor and equipment taking the time to roll the patch improves the performance. Higher costs for proprietary patching materials can also be justified based on their improved service lives.

The course has been offered 45 times since 2005. There have been 800 participants, including individuals from cities, towns, and villages; the state; counties; federal agencies; and commercial or private entities. The course is meeting a state need.

TABLE 10
COSTS OF DIFFERENT PATCHING TECHNIQUES

| Method | Throw-and-Go (standard cold patch) | Throw-and-Roll (standard cold patch) | Throw-and-Roll (proprietary cold patch) |
|---|---|---|---|
| Price ($/ton) | $45 | $45 | $72 |
| Materials | $900 | $900 | $1,440 |
| Labor | $676 | $901 | $901 |
| Equipment | $200 | $267 | $267 |
| Initial Cost | $1,776 | $2,068 | $2,608 |
| Survival Rate | 10% | 25% | 50% |
| Total Cost* | $4,813 | $4,782 | $4,564 |

*Source*: Orr (*81*).
*Assuming failed patches must be replaced three times.

CHAPTER SIX

# CONCLUSIONS

This chapter presents the various survey responses related to research needs, and then the overall findings of the synthesis are discussed and summarized. The findings are based on a review of the literature and surveys of state, local, and international roadway agencies. Well over 100 reports were reviewed for this synthesis. Survey responses were received from 49 of 51 state agencies—a response rate of 96.1%. In addition, 20 local U.S. agencies in eight states, five Canadian agencies, and 36 organizations in the United Kingdom and Ireland responded to similar surveys.

## IDENTIFIED RESEARCH CONDUCTED AND NEEDED

There has been a considerable amount of research done on pavement patching since the days of the initial Strategic Highway Research Program (SHRP). Much of that work has built on the SHRP research, continuing to evaluate some of the materials and practices addressed in SHRP and using some of the same tests and protocols. Other research has implemented an expanded suite of tests for particular applications and new patching materials. Research has also addressed management aspects of patching operations, particularly regarding the use of technology and computerized systems to track and analyze patching and other maintenance programs and their cost-effectiveness.

Research is still needed in several areas, judging by the survey responses. Approximately 30% of the states responding to the survey indicated they have sponsored or undertaken research. The primary areas of that research were in the performance of patching materials and cost-effectiveness, as shown in Figure 40. Figure 41 shows the number of states indicating a need for research concerning certain aspects of patching.

Of the 20 U.S. local agencies responding, none have sponsored research into patching; however, one is planning to study warrants and triggers for patching, management of patching activities, and cost-effectiveness. The agencies did report research needs, as shown in Figure 42. One local agency expressed a need for research on tools and materials for tacking and patching. As with the states, the greatest needs are for new materials and comparisons of materials. The perceived research needs are similar for both local and state agencies.

Few of the overseas agencies contacted have undertaken any research. Lack of adequate funding is the main reason. Of the seven respondents who reported being engaged in research, the performance of patching materials is the primary concern; cost-effectiveness is second.

## DISCUSSION AND CONCLUSIONS

Based on the literature review and surveys, the following general conclusions can be drawn:

- Patching pavements is one of the most widely practiced pavement maintenance activities. Every U.S. state uses patching to restore the functionality of distressed pavements, with most ranking it as a major component of their maintenance program. The few states that do not view patching as a major activity are mostly in warmer climates; cold weather definitely accelerates the development of potholes, the primary reason for patching. The percentage of the maintenance program budget that is spent on patching also varies widely. Comparisons are difficult because of the great diversity in the way patching is managed, if and how patching activities are tracked, and how costs are accounted for in the management system.
- Maintenance management programs are increasing in importance and complexity as states come to grips with rising costs, decreasing numbers of employees, and decreasing budgets. It is increasingly important to efficiently manage an activity as pervasive and expensive as pavement patching.
- Engineering judgment is still the primary consideration when selecting the type of maintenance activity. Engineers or maintenance foremen typically determine when a manually placed patch is to be used instead of a machine-placed patch, or when patching is not the right approach and more involved repairs are necessary.
- Guidelines are being used to supplement engineering judgment and improve consistency across an agency; however, those guidelines differ from agency to agency. The size of a distressed area that requires immediate action, for example, may vary.
- The triggers that call for patching and the distresses addressed are also reasonably consistent. Potholes; deterioration around joints, cracks, or previous patches; rutting; joint failure; delaminations; and spalling are the most common distresses that require patching.
- The need for patching is most commonly identified through visual identification, public complaints, emergency safety problems, and potholes.

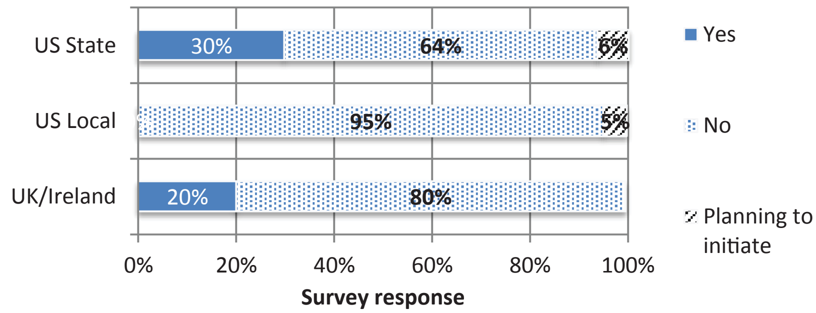



FIGURE 40 Comparison of U.S. state, local, and U.K. responses to "Have you undertaken research?" (*Source*: survey responses.)

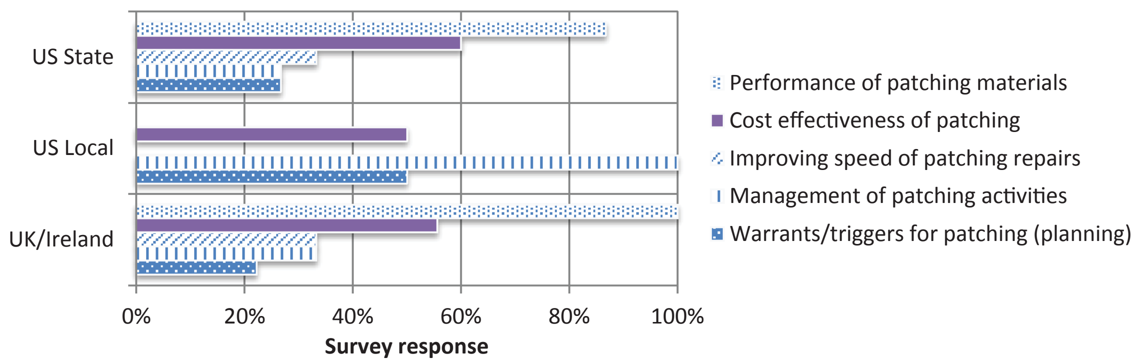



FIGURE 41 Areas of research undertaken (*Source*: survey responses.)

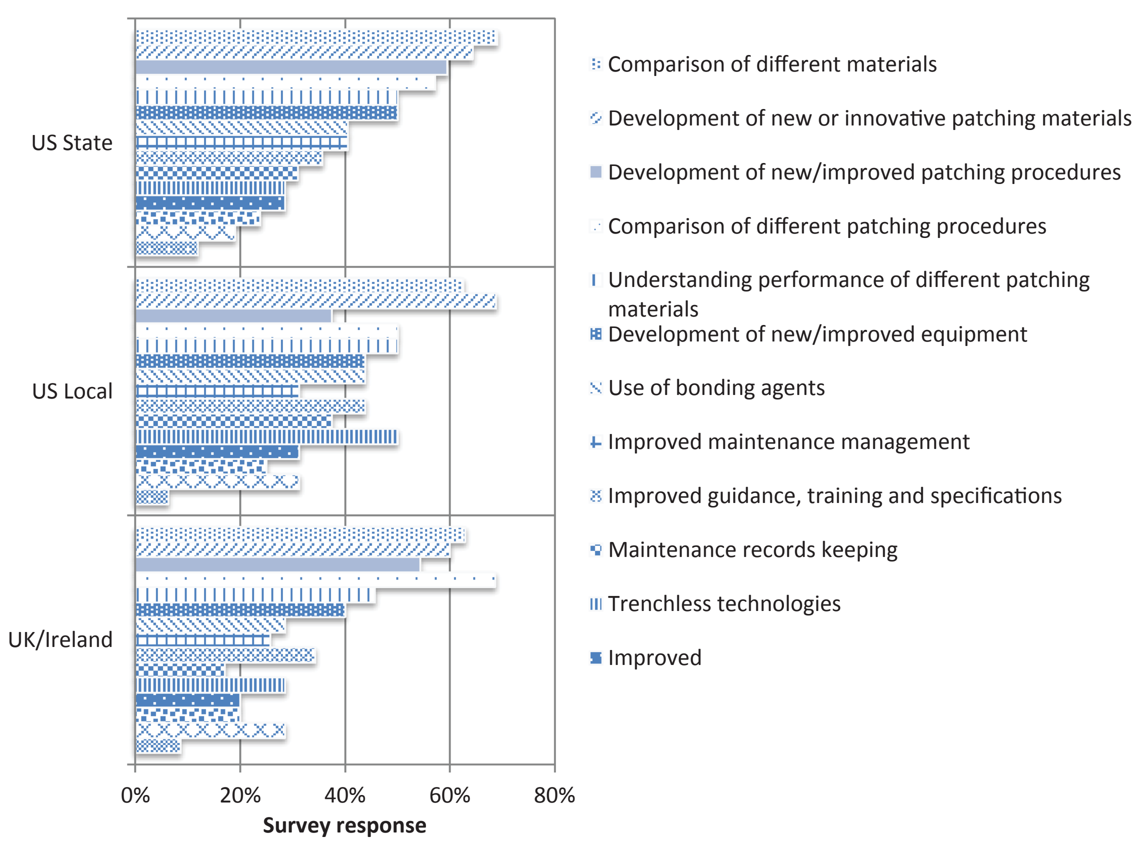



FIGURE 42 Percentages of agencies expressing needs for research on various topics (*Source*: survey responses.)

- Several states and ample research support the concept of "doing it right the first time." Making the right repair, however, depends on having the right materials, labor, equipment, traffic control, conditions, and, perhaps most importantly, funding. Research and experience show that the cost-effectiveness and level of service is greatly improved by avoiding the replacement of failed patches.
- The decision of whether to patch or do more extensive rehabilitation depends on a number of variables; therefore, guidelines for these decisions are not consistent between agencies. This is inevitable as costs, material availability, traffic, staff, and other factors vary.
- Knowledge of the causes of distress and failure mechanisms enables selection of the appropriate treatment; the right treatment will perform better and be more cost-effective.
- When patching is called for, the materials used fall into one of several categories. Cold mix, whether generic or proprietary, is routinely used for temporary patching. Hot mix is still the preferred patching material for semi-permanent patches in asphalt pavements. A wide range of cementitious patching materials is used for permanent patches on concrete pavements, with hot or cold asphalt mix for temporary patches.
- The cost of materials is relatively low compared with the other costs of patching, such as labor, equipment, and traffic control. This can help to justify the use of superior materials to avoid the need to replace failed patches.
- The throw-and-go patching method is not cost-effective and generally performs poorly.
- In most cases, when properly constructed, throw-and-roll patches can perform as well as sawed patches on asphalt pavements.
- State workforces are primarily responsible for reactive patching and much of the planned patching as well. Contractors are more often used when specialized equipment or expertise is needed.
- Maintenance contracts are growing in popularity, perhaps as a result of cutbacks in personnel. Some states are letting major maintenance contracts, particularly for interstates.
- Smaller agencies that cannot keep equipment and staff employed are more likely to contract out patching. On the other hand, some smaller agencies that do have staff available find it more cost-effective to do their own patching since they have the necessary staff on the payroll.
- Traffic management measures are somewhat consistent across agency lines, driven in large part by requirements outlined in the *Manual on Uniform Traffic Control Devices* (*MUTCD*). Agency guidelines also exist for the use of traffic control devices for moving or stationary operations on different types of roadways. Flaggers are commonly used for patching operations, as are cones and arrow boards. Signage and variable message boards are also used. Barriers and traffic signals are used much less frequently; typically only for major patching and slab replacement operations, often done under contract.

#### Changes in Patching Practices since SHRP

Research on patching conducted under the SHRP maintenance studies addressed materials and equipment for patching concrete and asphalt pavements. This synthesis compared today's practices to the SHRP recommendations. These comparisons lead to the following observations:

- The published SHRP research helped to standardize some of the terminology used to describe different patching techniques. The terms throw-and-go, throw-and-roll, semi-permanent, saw-and-patch, chip-and-patch, and others are widely recognized and understood today.
- The detailed, step-by-step installation procedures for these types of patches, as codified under SHRP, have been widely adopted—almost verbatim in some cases. States such as Tennessee and Indiana use these terms and steps in their maintenance guides.
- In many states, the saw-and-patch and semi-permanent patching techniques described in SHRP, calling for vertically cut faces, are widely prescribed even though several research studies have found that having a rough surface for the patch to adhere to (such as through the chip-and-patch or throw-and-roll techniques) may lead to better survivability of the patch.
- Spray injection patching was a fairly new technology at the time of SHRP. The SHRP research demonstrated the good performance of such patching when done by a skilled operator. Since SHRP the use of spray patching has increased dramatically in many states. The performance of the patches has generally been good in some states but not in others.
- The SHRP research also demonstrated good performance of proprietary patching materials in general. Use of these materials has increased in the years since, and new products are constantly being introduced to the market. Many states use proprietary materials routinely; others report having difficulties purchasing proprietary products. Approved lists of patching materials are used in some places to facilitate the purchase.
- Some of the tests recommended for evaluating these materials, such as the workability box and rolling sieve, are rarely used. Other SHRP-recommended tests such as coating, stripping, and draindown are sometimes used for initial approval of a patching material, but are less commonly used for routine quality testing.
- Partial-depth patching was shown through the SHRP research to be a feasible approach to patching concrete pavements. That is now a widely adopted practice across the country, although research is still being done to explore cost-effectiveness and evaluate patching materials and procedures for partial depth repairs. Since

SHRP, the depth considered for a partial-depth patch has been increased, in some cases from one-third to one-half the depth of the pavement.
- The automated patching machine developed under SHRP was never fully adopted as designed. The concept of using spray injection patching to reduce labor requirements, however, has been adopted in many agencies.

#### Comparison of State Practices with Local Agency and International Experience

A survey of highway agencies in cities and counties across the United States found that those agencies face many of the same pressures as the states and have adopted many of the same techniques and practices.

- Local agencies often face even tighter budgets, must make do with smaller workforces, and may be dealing with thinner roads, poorer drainage, and other factors leading to significant pavement distress. Perhaps it is not surprising then that local agencies tend to place great importance on their patching programs. Many of them are quite forward-thinking in terms of management and oversight of their patching practices.
- In terms of materials, equipment, and traffic control, the local and state agencies are in reasonably close alignment. Many local agencies use the state's guidelines and specifications. Local agencies tend to have fewer lane-miles of concrete pavement, so patching concrete is done less frequently.
- Maintenance by contract is also less common at local agencies. In many, there is a maintenance work force on the payroll; therefore, there is a need to keep them occupied, so they may as well be placing patches. Also, the typically smaller budgets of most local agencies may make patching by contract less feasible. In other cases, local agencies prefer maintenance contracts because they cannot afford to maintain staff and equipment.

Despite differences in how agencies are structured and terminology used, overall, the practices in the United Kingdom and Ireland are quite similar to those in the U.S. states and local agencies.

Similarities and differences can be outlined as follows:

- One difference between the United States and the United Kingdom and Ireland is in the use of maintenance contractors. That practice is much more common overseas, even for local agencies. Some overseas counties and municipalities find it more cost-effective to contract out maintenance than to invest in building their own workforce and procuring equipment for their small networks.
- The patching materials used are similar, as are the distresses and triggers. Spray patchers are also commonly used overseas, especially in larger jurisdictions and by contractors.
- Similarly, no major differences were observed between the Canadian and U.S. survey responses; however, the number of Canadian agencies responding was quite small and may not have been comprehensive and representative.

### GAPS IN THE KNOWLEDGE AND FUTURE RESEARCH NEEDS

Among the previously identified research needs expressed through the survey, subsequent communications as a part of this synthesis revealed the following gaps in the state of knowledge and needs for improvement. Participants in this synthesis reported needing:

- Ways to speed up patching operations, which could include more automated patching and more private sector developments.
- Hands-on training for employees.
- Equipment for using recycled asphalt pavement to patch.
- Evaluating patching as a pavement preservation technique.
- Safer traffic control measures for short duration patching.
- The true costs of patching, including all associated costs, such as labor, equipment, and traffic control.
- Improved methods for tracking patch locations and the materials and techniques used to aid in evaluating performance and cost-effectiveness of patching options.
- Investigation into the reasons why spray patching is so successful in some states and not in others.

Similar research needs were suggested by state, local, and international agencies.

In addition, all the agencies were asked where they would invest more money if the funding were available. The responses are summarized in Figure 43. Procuring better materials was a high priority for all types of respondents; however, U.S. local agencies reported even higher needs for more and better patching equipment. Increased staffing was also a high priority. Research and "other" were less highly rated. More than 30% of all respondents would increase funding for all of the previous items.

### SUMMARY

As one of the most common and expensive maintenance techniques practiced by highway agencies, improvements in managing patching activities, techniques, and materials could have

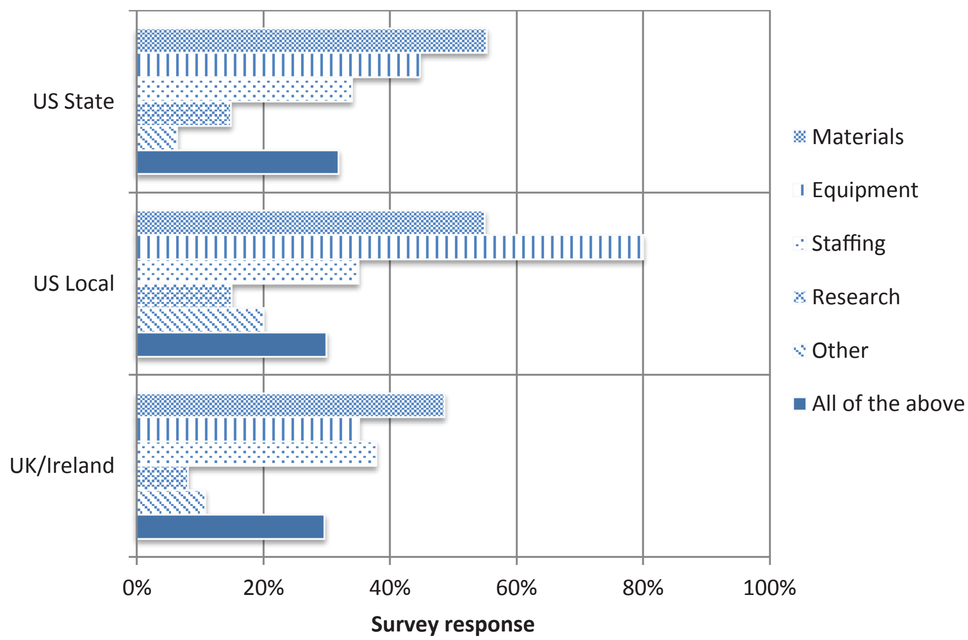



FIGURE 43 Resource needs identified (*Source*: survey responses.)

a major impact on budgets and pavement performance. This synthesis summarizes the state of the practice and updates the information available on patching practices to help agencies make informed decisions.

The overall findings suggest that there are striking similarities and, similarly, striking differences in how agencies manage their programs. There is apparently more consistency in the materials used, partly because of what is available in the market, but also because some materials work better in some situations than others. No major differences were observed between practices in the United States, Canada, the United Kingdom, and Ireland.

Lastly, while there have been improvements since the SHRP research on pothole patching and spall repair, there are still significant research needs across agencies, suggesting that a coordinated research effort would be beneficial.

# REFERENCES


1. Kuo, S.-S., L. Carlo, and C. Kuenzel, *Evaluation of Patching Materials and Placement Techniques for Rigid Pavements and Bridge Decks*, Final Report, Florida Department of Transportation, Tallahassee, 1999.
2. Miller, J.S. and W.Y. Bellinger, *Distress Identification Manual for the Long-Term Pavement Performance Program*, Fourth Revised Edition, Federal Highway Administration, McLean, Va., 2003.
3. Evans, L.D., C.G. Mojab, A.J. Patel, A.R. Romine, K.L. Smith, and T.P. Wilson, *Innovative Materials Development and Testing, Volume 1: Project Overview*, Report No. SHRP-H-352, Transportation Research Board, National Research Council, Washington, D.C., 1993.
4. Wilson, T.P. and A.R. Romine, *Manual of Practice: Materials and Procedures for the Repair of Potholes in Asphalt-Surfaced Pavements*, Report No. SHRP-H-348, Transportation Research Board, National Research Council, Washington, D.C., 1993.
5. Wilson, T.P. and A.R. Romine, *Materials and Procedures for Repair of Potholes in Asphalt-Surfaced Pavements—Manual of Practice*, Report FHWA-RD-99-168, Federal Highway Administration, McLean, Va., 1999.
6. Mojab, C.A., A.J. Patel, and A.R. Romine, *Innovative Materials Development and Testing, Volume 5: Partial Depth Spall Repair in Jointed Concrete Pavements*, Report No. SHRP-H-356, Transportation Research Board, National Research Council, Washington, D.C., 1993.
7. Smith, K.L., D.G. Peshkin, E.H. Rmeili, T. Van Dam, K.D. Smith, and M.I. Darter, *Innovative Materials and Equipment for Pavement Surface Repairs, Vol. 1: Summary of Material Performance and Experimental Plans*, Report No. SHRP-M/UFR-91-504, Transportation Research Board, National Research Council, Washington, D.C., 1991.
8. Wilson, T.R., "Strategic Highway Research Program Pothole Repair Materials and Procedures," *Transportation Research Record 1392*, Transportation Research Board, National Research Council, Washington, D.C., pp. 27–32.
9. Wilson, T.P. and A.R. Romine, *Innovative Materials Development and Testing, Volume 2: Pothole Repair*, Report No. SHRP-H-353, Transportation Research Board, National Research Council, Washington, D.C., 1993.
10. Federal Highway Administration (FHWA), *TechBrief, Pothole Repair*, Report FHWA-RD-99-202, FHWA, McLean, Va., 1999.
11. Wilson, T.P., K.L. Smith, and A.R. Romine, *LTPP Pavement Maintenance Materials: PCC Partial-Depth Spall Repair Experiment*, Final Report, Report FHWA-RD-99-153, Federal Highway Administration, McLean, Va., 1999.
12. Wilson, T.P., K.L. Smith, and A.R. Romine, *Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements—Manual of Practice*, Report FHWA-RD-99-152, Federal Highway Administration, McLean, Va., 1999.
13. Federal Highway Administration (FHWA), *TechBrief, Portland Cement Concrete* (*PCC*) *Partial-Depth Spall Repair*, Report FHWA-RD-99-177, FHWA, McLean, Va., 1999.
14. Blaha, J.R., *Fabrication and Testing of Automated Pothole Patching Machine*, Report No. SHRP-H-674, Transportation Research Board, National Research Council, Washington, D.C., 1993.
15. Anderson, D.A. and H.R. Thomas, "Pothole Repair in Pennsylvania," *Proceedings of Purdue University's 70th Annual Road School*, West Lafayette, Ind., 1984, pp. 28–46.
16. Anderson, D.A., H.R. Thomas, Z. Siddiqui, and D.D. Krivohlavek, *More Effective Cold Wet-Weather Patching Materials for Asphalt Pavements*, Report FHWA-RD-88-001, Pennsylvania State University, University Park, 1987.
17. Pennsylvania Transportation Institute, *Pothole Repair: A Guide for PaDOT Maintenance Crews*, Pennsylvania State University, University Park, 1980.
18. Thomas, H.R., "A Procedure for Evaluating the Efficiency of Power-Operated Cutting Tools in Localized Pavement Repair," *Transportation Research Record 1392*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 24–29.
19. Feighan, K.J., E.A. Sharaf, T.D. White, and K.C. Sinha, "Estimation of Service Life and Cost or Routine Maintenance Activities," *Transportation Research Record 1102*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 13–21.
20. Kuennen, T., "The Pothole Patching Playbook: Why Potholes Occur, How to Patch Them, and How to Prevent Them in the First Place, *Better Roads*, Vol. 74, 2004, pp. 30–41.
21. Peshkin, D.G. and T.E. Hoerner, *Pavement Preservation: Practices, Research Plans and Initiatives*, Final Report, NCHRP Project 20-07, Task 184, Transportation Research Board, National Research Council, Washington, D.C., 2005 [Online]. Available: http://maintenance.transportation.org/Documents/NCHRP20-07184FinalReport.pdf [accessed Mar. 28, 2013].
22. Lee, J. and T. Shields, *Treatment Guidelines for Pavement Preservation*, Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Ind., 2010.
23. Sinha, K.C., M. Saito, and J. Nafakh, "Optimization of Equipment Use in Routine Highway Maintenance," *Transportation Research Record 1148*, Transportation

Research Board, National Research Council, Washington, D.C., 1987, pp. 38–47.

24. Saito, M., K.C. Sinha, and E.A. Sharaf, "Analysis of Fuel Consumption in Routine Maintenance of State Highways in Indiana (abridgement)," *Transportation Research Record No. 1102*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 22–26.
25. Illinois DOT, press releases [Online]. Available: dot.state.il.us/districtreleases.htm [accessed June 30, 2013].
26. Pennsylvania Department of Transportation, Maintenance First, Manual Patching [Online]. Available: ftp.dot.pa.us/public/PubsForms/Publications/PUB 370E.pdf.
27. Potholepalooza, District of Columbia Department of Transportation [Online]. Available: ddot.dc.gov/potholes/ [accessed May 5, 2013].
28. District of Columbia Department of Transportation [online]. Available: http://ddot.dc.gov/release/ddot-crews-fill-almost-12000-potholes-during-potholepalooza [accessed June 9, 2014].
29. *The Daily Pothole*, a Publication of New York City Department of Transportation [Online]. Available: the dailypothole.tumblr.com [accessed June 15, 2013].
30. Missourinet [Online]. Available: www.missourinet.com/2013/03/19/department-of-transportation-launches-statewide-pothole-clean-up-effort-audio [accessed Mar. 20, 2013].
31. Caltrans Division of Maintenance, *Maintenance Technical Advisory Guide, Vol. 1—Flexible Pavement Preservation*, 2nd ed., California Department of Transportation, Sacramento, 2008.
32. Maher, A., N. Gucunski, W. Yanko, and F. Petsi, *Evaluation of Pothole Patching Materials*, Report FHWA 2001-02, Rutgers University, Piscataway, N.J., 2001.
33. Dong, Q., B. Huang, and X. Shu, "Field and Laboratory Evaluation of Winter Season Pavement Patching Materials in Tennessee," Paper No. 13-4772, Transportation Research Board 92nd Annual Meeting Compendium, 2013.
34. *Maintenance Manual*, Idaho Transportation Department, Boise, 2012.
35. *Field Operations Guide*, Transportation Cabinet, Commonwealth of Kentucky, Frankfort, 2011.
36. *Maintenance Manual*, Washington State Department of Transportation, Olympia, 2010.
37. *Maintenance Manual*, Montana Department of Transportation, Helena, 2009.
38. *Standard Specifications*, "Pothole Repair," Texas Department of Transportation, Austin, 2004, p. 981.
39. *Maintenance Manual*, Chapter 3, Minnesota Department of Transportation, St. Paul, 2005.
40. Johnson, A., *Best Practices Handbook on Asphalt Pavement Maintenance*, Manual No. 2000-04, University of Minnesota Center for Transportation Studies, Minneapolis, 2000.
41. Rosales-Herrera, V.I., J. Prozzi, and J.A. Prozzi, *Mixture Design Manual and Performance-Based Specifications for Cold Patching Mixtures*, report submitted to FHWA and TxDOT, Austin, Tex., 2007, 144 pp.
42. Frick, K., *Evaluation of New Patching Material for Open-Graded Asphalt Concrete (OGAC) Wearing Courses*, Technical Memorandum UCPRC-TM-2005-9, University of California Pavement Research Center, Davis and Berkeley, 2005.
43. Conigliaro, A. and P. Watson, *Determining the Best Formulation for a Unique Asphalt Cold Patch Product Made With #3-7 Rigid Plastic Aggregate*, report submitted to Chelsea Center for Recycling and Economic Development, Chelsea, Mass., 2000, p. 8.
44. Clyne, T.R., E.N. Johnson, and B.J. Worel, *Use of Taconite Aggregates in Pavement Applications*, Minnesota Department of Transportation, St. Paul, 2010, p. 21.
45. Latta, J., "A Magic Mix of Magnetite and Microwaves Offers a Super Year-Round Pothole Fix," *Better Roads*, 2013 [Online]. Available: http://www.betterroads.com/hot-holes/?full-article=true [accessed Aug. 9, 2013].
46. Estakhri, C.K. and J.W. Button, "Test Methods for Evaluation of Cold-Applied Bituminous Patching Mixtures," *Transportation Research Record 1590*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 10–16.
47. Guthrie, W.S. and K. Woffinden, "Improving Patch Joint Bonder Strength," *Public Works*, No. 5, 2004, pp. 35–37.
48. Freeman, T.J. and J. Epps, *HeatWurx Patching at Two Locations in San Antonio*, Texas Transportation Institute, Report No. 5-9043-01-1, Austin, 2012.
49. Uzarowski, L., V. Henderson, M. Henderson, and B. Kiesswetter, "Innovative Infrared Crack Repair Method," *Annual Conference of the Transportation Association of Canada*, Edmonton, AB, Canada, 2011.
50. Prowell, D.B. and A.G. Franklin, "Evaluation of Cold Mixes for Winter Pothole Repair," *Transportation Research Record 1529*, Transportation Research Board, National Research Council, Washington, D.C., 1996, pp. 76–85.
51. Wei, C. and S. Tighe, "Development of Preventive Maintenance Decision Trees Based on Cost-Effectiveness Analysis: An Ontario Case Study," *Transportation Research Record: Journal of the Transportation Research Board, No. 1866*, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 9–19.
52. Palsat, D.P., H. Soleymani, D.E. Mesher, and P. Campbell, "Developing a Performance-Based Specification for Spray-Patch Crack Treatment—A Case Study in Alberta," Canadian Technical Asphalt Association, *Proceedings*, Vol. 53, 2008, pp. 1–28.
53. Smith, K.D., *Tech Brief: Concrete Pavement Rehabilitation and Preservation Treatments*, Concrete Pavement Technology Program, Federal Highway Administration, Washington, D.C., 2005.
54. *Maintenance Technical Advisory Guide, Vol. II—Rigid Pavement Preservation*, 2nd ed., Caltrans Division of

Maintenance, California Department of Transportation, Sacramento, 2008.

55. *Concrete Manual*, Minnesota Department of Transportation, St. Paul, 2003.
56. *Standard Specifications for Road and Bridge Construction*, Wyoming Department of Transportation, Cheyenne, 2010.
57. Rangaraju Rao, P. and R. Pattnaik Ranjan, *Evaluation of Rapid Set Patching Materials for PCC Applications*, Report FHWA-SC-07-07, Clemson University, Clemson, S.C., 2008.
58. National Transportation Product Evaluation Program (NTPEP), *Two-Year Report of Field Performance and Laboratory Evaluations of Rapid Setting Patching Materials for Portland Cement Concrete—June 2007 Product Submissions*, NTPEP Report 9008.2, American Association of State Highway and Transportation Officials, Washington, D.C., 2009.
59. Kuo, S.-S., J.M. Armaghani, and D. Scherling, *Accelerated Pavement Performance Testing of Ultra-Thin Fiber Reinforced Concrete Overlay, Recycled Concrete Aggregate, and Patching Materials*, University of Central Florida, Orlando, 2000.
60. Hanson, T.D., *Blended Cement Patching Research*, Final Report for MLR-04-01, Iowa Department of Transportation, Ames, 2005.
61. Bischoff, D. and A. Toepel, *Dowel Bar Retrofit: STH 13 Construction and One-Year Performance Report*, Report No. WI-07-02, Wisconsin Department of Transportation, Madison, 2002.
62. Bischoff, D. and A. Toepel, *Laboratory Testing of Portland Cement Concrete Patch Material, Modified to Reduce or Eliminate Shrinkage*, Report No. WI-01-04, Wisconsin Department of Transportation, Madison, 2004.
63. Priddy, L.P., S.R. Jersey and R.B. Freeman, "Determining Rapid-Setting Material Suitability for Expedient Pavement Repairs: Full-Scale Traffic Tests and Laboratory Testing Protocol," *Transportation Research Record: Journal of the Transportation Research Board, No. 2113*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 140–148.
64. Soltesz, S., M. Dunning, M. Joerger, and J. Lundy, *Concrete Patching Guide*, Report No. SPR #334, Oregon Department of Transportation, Salem, 2003.
65. *Partial-Depth Repair of Portland Cement Concrete Pavements*, Construction Inspection Checklist #09, Federal Highway Administration, Washington, D.C., 2005 [Online]. Available: www.fhwa.dot.gov/pavement/pub_details.cfm?id=350 [accessed May 24, 2013].
66. *Partial-Depth Repairs*, Federal Highway Administration, Washington, D.C., 2011 [Online]. Available: www.fhwa.dot.gov/pavement/concrete/repair.cfm [accessed May 24, 2013].
67. Frentress, D.P. and D.S. Harrington, *Guide for Partial-Depth Repair of Concrete Pavements*, Institute for Transportation, Iowa State University, Ames, 2012.
68. Hammons, M. and A. Saeed, "Expedient Spall Repair Methods and Equipment for Airfield Pavements," *Transportation Research Record: Journal of the Transportation Research Board, No. 2155*, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 63–70.
69. Yuan, Z. and C.P. Liu, "Analysis on Upper Limit of Patching Area of Corner Breaks," *Geotechnical Special Publication No. 223*, *Road Materials and New Innovations in Pavement Engineering*, American Society of Civil Engineers, Reston, Va., 2011, pp. 144–150.
70. Browning, G., *Evaluation of RESURF CR*, Study No. 67-24, Mississippi Department of Transportation and FHWA, Jackson, Miss., 1999.
71. Chen, D., J. Li, and J. Xie, "Performance of Fiber Reinforced Polymer Patching Binder for Minimizing Reflective Cracking," *Geotechnical Special Publication No. 212*, *Pavements and Materials*, American Society of Civil Engineers, Reston, Va., 2011.
72. Chen Hao, D., C.M. Won, Q. Zhang, and T. Scullion, "Field Evaluations of the Patch Materials for Partial-Depth Repairs," *Journal of Materials in Civil Engineering*, Vol. 21, 2009, pp. 518–522.
73. Markey, S.M., S.I. Ilee, A.K. Mukhopadhyay, D.G. Zollinger, D.P. Whitney and D.W. Fowler, *Investigation of Spall Repair Materials for Concrete Pavement*, Report No. 0-5110-1, Texas Transportation Institute, Texas A&M University, College Station, 2006.
74. Lugg, M.D., "The Pothole Review—Prevention and a Better Cure," Transportation Research Board 92nd Annual Meeting Compendium, Paper No. 13-3593, 2013.
75. Pollock, R., *A Review of State-of-the-Art Practices for Patching Asphalt and Concrete Pavements*, Project Dissertation for the Degree of BEng, Queen's University Belfast, 2013.
76. *Well-Maintained Highway: Code of Practice for Highway Maintenance Management*, U.K. Department of Transport, London, 2011.
77. *Maintenance Quality Assurance Manual*, Maintenance Division, Indiana Department of Transportation, Indianapolis, 2011.
78. *Work Zone Traffic Control Guidelines*, Work Zone Safety Section, Indiana Department of Transportation, Indianapolis, 2013.
79. *2012 Stormwater Report*, Washington State Department of Transportation, Olympia, 2012.
80. *Guidelines for Addressing Potholes Repairs*, Marion County Public Works, Salem, Ore., 2008.
81. Orr, D.P., *Pavement Maintenance*, Cornell Local Roads Program, Ithaca, N.Y., 2006.

# APPENDIX A

## Screening Questionnaire

### NCHRP Pavement Patching Practices Synthesis

The Transportation Research Board is preparing a synthesis on Pavement Patching Practices. The synthesis is being performed under National Cooperative Highway Research Program (NCHRP) Project 20-05 as Synthesis Topic 44-04. This questionnaire is part of the information-gathering effort for that study.

While patching is probably the most common method of addressing immediate pavement repair and maintenance needs, there is currently a lack of updated national information and guidance regarding this topic. Recognizing this need, NCHRP has initiated this synthesis project to document the state of highway practice related to pavement patching. The main focus of this project is on small-scale, reactive types of repairs on both asphalt and concrete pavement surfaces. We are also seeking information on planned patching activities and the use of automated machines for pavement patching for comparison. Similar questions will also be posed to agencies in Europe and other parts of the world to identify potentially beneficial practices used overseas.

The terms reactive and planned are used in this survey to differentiate between those patching activities that arise suddenly and require immediate action (reactive or emergency repairs) and those that may appear more gradually so that fixing them can be planned or predicted in advance. In addition, the term temporary is used to describe patches that are placed as a short-term repair until a more permanent patch or other repair/rehabilitation/replacement can be completed.

The final report on this study will document the results of this survey, as well as more detailed follow-up interviews with selected agencies and a comprehensive literature search. It is expected to be of considerable value to transportation agencies in need of information that can help them improve their pavement patching practices.

This survey is being sent to all State Departments of Transportation. Your cooperation in completing the questionnaire will help to ensure the success of this effort. We estimate that completion of this questionnaire should not take more than 15-20 minutes. We respectfully request that this survey be completed and submitted by March 31, 2013.

If you prefer, you may respond to these or any other questions by phone. To do so, please contact Becky McDaniel, the PI for this project, either by email at rsmcdani@purdue.edu or by phone at 765-463-2317, ext 226, to arrange a date and time.

# NCHRP Pavement Patching Practices Synthesis

**General Information. Please provide your contact information.**

Name:

Position/Title:

Agency:

Address:

City/Town:

State/Province:

ZIP/Postal Code:

Country:

Email Address:

Phone Number:

**May we contact you for additional information?**

- ◯ Yes.
- ◯ No.
- ◯ Instead, please contact (name and phone or email):

**1. Do you consider pavement patching to be a major component of your organization's maintenance operations?**

- ◯ Yes.
- ◯ No.

**2. Do you have an established methodology for determining where patching is needed in your area?**

- ◯ Yes.
- ◯ No.

## NCHRP Pavement Patching Practices Synthesis

**3. Is there a trigger that calls for patching? (Click all that apply.)**

- [ ] Visual identification
- [ ] Area or depth of pothole
- [ ] Depth of rutting
- [ ] Extent of cracking
- [ ] Roughness/ravelling
- [ ] Width of joint
- [ ] Extent of scaling or spalling
- [ ] Public complaints
- [ ] Poor ride quality
- [ ] Sudden safety problems

Other(s) (please specify)

**4. If known, what is the average annual extent of patching repairs in your jurisdiction? (Please choose appropriate unit of measurement and insert estimate of average annual value.)**

| | |
|---|---|
| Number of patches per mile | |
| Area of patches per mile | |
| Volume of patching material used per mile | |
| Percent of maintenance program | |
| Other(s) | |

## NCHRP Pavement Patching Practices Synthesis

**5. What are the most common pavement distresses that require patching? (Click all that apply.)**

- [ ] Potholes
- [ ] Rutting
- [ ] Delamination
- [ ] Material distress (ASR, D-cracking)
- [ ] Raveling
- [ ] Segregation
- [ ] Deterioration at a paving joint (asphalt surface)
- [ ] Spalling
- [ ] Joint failure (concrete surface)
- [ ] Deterioration around cracks
- [ ] Deterioration of or around a previous patch
- [ ] Corner Breaks
- [ ] Blowups
- [ ] Faulting
- [ ] Punchouts

Other(s) (please specify)

**6. Typically, how much time elapses between your organization becoming aware of or planning patching repairs and the completion of the patch?**

| | Time to repair |
|---|---|
| Reactive Patching | |
| Planned Patching | |

**7. Does your organization have, or work from, specifications, plans or guidelines for patching?**

| | |
|---|---|
| Reactive | |
| Planned | |
| Temporary | |
| Permanent | |

## NCHRP Pavement Patching Practices Synthesis

**8. What materials are used for patching asphalt pavements in your area? (Check all that apply .)**

- [ ] Generic stockpile mix
- [ ] Proprietary asphalt mix
- [ ] Hot asphalt mix
- [ ] Warm Mix Asphalt
- [ ] Spray emulsion and aggregate (a.k.a. spray patcher or blow patcher)
- [ ] Polymeric Materials (e.g., epoxy)
- [ ] Crumb Rubber Mastic

Other(s) (please specify)

**9. What materials are used for patching concrete pavement in your area? (Click all that apply.)**

- [ ] Asphalt patching material
- [ ] Normal hydraulic cement mixtures (with or without accelerators)
- [ ] Rapid strength hydraulic cement concrete mixtures
- [ ] Other rapid setting cement mixtures (e.g., calcium aluminate, calcium sulfoaluminate, magnesium phosphate)
- [ ] Gypsum-based cement mixtures
- [ ] Epoxy mixtures
- [ ] Latex or polymer-modified concrete

Other(s) (please specify)

**10. Does your organization have any QC/QA procedures that are implemented at the time of patch placement?**

- ◯ Yes.
- ◯ No.

If yes, what properties do you measure? (E.g., density, strength, stiffness, smoothness, etc.)

## NCHRP Pavement Patching Practices Synthesis

**11. Do you use any form of automated equipment/machines for placing patching?**

- ◯ Yes.
- ◯ Yes, but only for patching by contract.
- ◯ No.

**12. Who places patches in your jurisdiction?**

| | Reactive Patching | Planned Patching |
|---|---|---|
| State forces | ☐ | ☐ |
| Paving contractor | ☐ | ☐ |
| Specialty contractor | ☐ | ☐ |
| Other(s) | ☐ | ☐ |

If other(s), please specify

**13. What types of traffic management procedures do you use for patching activities? (Click all that apply.)**

| | Reactive | Planned |
|---|---|---|
| Flaggers | ☐ | ☐ |
| Lane closure with cones | ☐ | ☐ |
| Lane closure with arrow boards | ☐ | ☐ |
| Lane closure with barriers | ☐ | ☐ |
| Flashing lights and arrows on truck/equipment | ☐ | ☐ |
| Traffic signals | ☐ | ☐ |
| None | ☐ | ☐ |
| Other(s) | ☐ | ☐ |

If other(s), please specify.

**14. Do you monitor the performance of installed patches?**

| | Reactive | Planned |
|---|---|---|
| Yes. | ☐ | ☐ |
| Yes, but only for patching by contract. | ☐ | ☐ |
| No. | ☐ | ☐ |

**15. Do you have an established methodology to track the location of patches that have been placed in your area?**

| | Reactive | Planned |
|---|---|---|
| Yes. | ☐ | ☐ |
| No. | ☐ | ☐ |

## NCHRP Pavement Patching Practices Synthesis

**16. What is the average unit cost of patches in your area? Please provide as much detail as you can using whatever unit of measure you use. (For example: costs per ton, patch, mile, area, etc.; costs for temporary vs. permanent, reactive or planned, different types of materials, manual or automated, state forces vs. contract, etc.).**

**17. Has your organization undertaken or sponsored research in the area of patching?**

- ☐ Yes.
- ☐ No.
- ☐ Planning to initiate research.

**If yes to the question above, what are the main areas of research?**

- ☐ Performance of patching materials
- ☐ Warrants/triggers for patching (planning)
- ☐ Management of patching activities
- ☐ Improving speed of patching repairs
- ☐ Cost effectiveness of patching
- ☐ Other(s)

Who could we contact for more information on this research? (Name and phone or email.)

## NCHRP Pavement Patching Practices Synthesis

**18. Is there a need for more research or information on (click all that apply):**

- [ ] Comparison of different materials?
- [ ] Comparison of different patching procedures?
- [ ] Development of new or innovative patching materials?
- [ ] Development of new or improved patching procedures?
- [ ] Development of new or improved equipment?
- [ ] Understanding of causes of distresses needing patching?
- [ ] Understanding of the performance of different patching materials?
- [ ] Improved maintenance (patching) management?
- [ ] The way maintenance (patching) records are kept and what they contain?
- [ ] Improved guidance, training and specifications?
- [ ] Improved patching standards?
- [ ] Use of bonding agents?
- [ ] Coordination of road repairs where possible? (e.g., between utilities and road agency)
- [ ] Use of trenchless technologies to reduce the number of road cuts and hence potential patch failures?
- [ ] Other(s) (please specify)

**19. If your agency were able to invest more money in pavement patching activities, what would be the priority areas to fund?**

- [ ] Research
- [ ] Staffing
- [ ] Equipment
- [ ] Materials
- [ ] All of the above
- [ ] Other(s) (please specify)

**20. Do you have any additional comments or information? (Optional)**

This completes the survey. Thank you for your time and information.

# APPENDIX B

## Survey Respondents

TABLE B1
U.S. RESPONDENTS

| Agency | Name | Title |
|---|---|---|
| AL | Ron Newsome | Transportation Administrator—Roadway |
| AK* | Tom Williams | Maintenance Superintendent |
| AZ | Marwan Aouad, Ph.D., P.E. | Assistant State Maintenance Engineer |
| AR | Tony Sullivan | State Maintenance Engineer |
| CA | Peter Vacura | Chief, Office of Flexible Pavement |
| CO | David C. Wieder | Maintenance & Operations Branch Manager |
| CT* | Ed F. Girolamo | Maintenance Planner |
| DE | Jim Pappas | Assistant Director |
| DC | Frank Pacifico | Street & Bridge Maintenance Manager |
| FL* | Tim Allen | Roadside Manager |
| GA* | Jimmy Witherow | Liaison |
| HI | JoAnne Nakamura | |
| ID* | Steve Spoor | Maintenance Services Manager |
| IL* | Justan Mann | Engineer of Operations |
| IN* | Bill Tompkins | Field Maintenance Engineer |
| IA | Robert A. Younie | State Maintenance Engineer |
| KS | Robert A. Fuller | Staff Engineer |
| KY | Jon Wilcoxson | TEBM |
| LA* | William D. Drake, Jr. | Roadway Maintenance Management Engineer |
| ME* | Brian Burne | Highway Maintenance Engineer |
| MD* | Len Schultz | Division Chief, Highway Maintenance |
| MA | Edmund Naras | Pavement Management Engineer |
| MI* | Curtis Bleech | Pavement Operations Engineer |
| MN* | Cliff Gergen | TOS4 |
| MS* | Mark Holley | District Maintenance Engineer |
| MO* | Dave Hand | Maintenance Operations Manager |
| MT | R. Todd Miller | Maintenance Liaison Engineer |
| NE | Mike Mattison | Maintenance Engineer |
| NV* | Jeffrey Dodge | Maintenance |
| NH | Caleb Dobbins | State Maintenance Engineer |
| NJ | Richard M. Shaw | Assistant Commissioner |
| NM | Robert S. Young | Pavement Preservation Engineer |
| NY* | Stacey Forenz | ARDO |
| NC | Judith Corley-Lay | State Pavement Management Engineer |
| ND | David Bruins | Transportations Engineer |
| OH* | Aric Morse | Pavement Engineer |
| OK | Alex Calvillo | Assistant State Maintenance Engineer |
| OR | Lucinda M. Moore | Maintenance and Operations Engineer |
| PA* | Kim Martin | Chief of Maintenance and Performance |
| RI* | Joseph D. Baker | Administrator |
| SC* | Jim Feda | Director of Maintenance |
| TN* | Greg Duncan | Assistant Chief Engineer of Operations |
| TX | Magdy Mikhail | Director Pavement Preservation Section |
| UT | Lynn Bernhard | Maintenance Methods Engineer |
| VT | Wayne Gammell | Maintenance Transportation Administrator |
| VA | Emmett Heltzel | State Maintenance Engineer |
| WA* | Jeff Uhlmeyer | State Pavement Engineer |
| WI | Allan Johnson | Assistant State Maintenance Engineer |
| WY | Kent Ketterling | State Maintenance Engineer |

*Follow-up contact/interview.

TABLE B2
LOCAL AGENCY RESPONDENTS

| State | Agency | Name | Title |
|---|---|---|---|
| CO | Arapahoe County | Jon Heese | Engineering Inspector |
| CO | La Plata County | Doyle Villers | Superintendent of Road Maintenance |
| CO | Otero County | Darren Garcia | Road & Bridge Coordinator/Supervisor |
| IN | Crawfordsville Street Department | Scott Hesler | Street Commissioner |
| IN | City of Greenfield Street Department | Jim Hahn | Street Commissioner |
| IN | City of Hobart | John Dubach | Director Public Works |
| IN | City of Jasper Street Department | Raymie Eckerle | Street Commissioner |
| IN | Noble County Highway Department | Mark Goodrich | Superintendent |
| OH | City of Akron Ohio | Steve Batdorf | Highway Maintenance Superintendent |
| OH | Defiance County | Warren Schlatter | County Engineer |
| OR | City of Gresham | Dennis Hughes | Pavement Manager |
| OR* | Marion County, Oregon | Don Newell | Operations Manager |
| OR | City of Oregon City Public Works | Kevin Hanks | Street Department Supervisor |
| NY* | Cornell Local Roads Program | David P. Orr, PE | Senior Engineer |
| TX | Bandera County | John Andrade | Road Superintendent |
| UT | Utah LTAP | Nick Jones | Director |
| WA | Kitsap County Public Works | Don Schultz | Road Supt./Sr. Program Manager |
| WA | City of Marysville | Jeff Laycock | Project Manager |
| WA | City of Mercer Island | Clint Morris | Street Manager |
| WA | Spokane County | Howard Hamby | Pavement Manager |

*Follow-up.

TABLE B3
UK AND IRELAND RESPONDING ORGANIZATIONS

| Country | Organization | Authority |
|---|---|---|
| England | Connect Roads | National |
| | Nottinghamshire County Council | Regional |
| | Durham County Council | Regional |
| | Leicestershire County Council | Regional |
| | Isle of Wight Council | Regional |
| | Gateshead Council | Local |
| | Hartlepool Borough Council | Local |
| | Sunderland City Council | Local |
| | North Tyneside Council | Local |
| | Redcar & Cleveland Borough Council | Local |
| Wales | Vale of Glamorgan Council | Regional |
| | Monmouthshire County Council | Regional |
| | City and County of Swansea Council | Regional |
| | Denbighshire County Council | Regional |
| | Merthyr Tydfil County Borough Council | Local |
| | Newport City Council | Local |
| | Rhondda Cynon Taf County Borough Council | Local |
| | Bridgend County Borough Council | Local |
| Northern Ireland | DRD Roads Service (x3) | National |
| | Farrans Constructions (x3) | National |
| | Graham/HMM | National |
| Scotland | WSP | National |
| | Falkirk Council | Regional |
| | Perth & Kinross Council | Regional |
| | Scottish Borders Council | Regional |
| | East Lothian Council | Regional |
| | City of Edinburgh Council | Local |
| Ireland | Kildare County Council | Regional |
| | Limerick County Council | Regional |
| | Monaghan County Council | Regional |
| | Cork City Council | Regional |
| | Kerry County Council | Regional |

TABLE B4
CANADIAN RESPONDENTS

| Agency/Organization | Name | Title |
|---|---|---|
| City of Calgary | Joe Chyc-Cies | Materials and Research Engineer |
| City of Edmonton | Al Cepas | Pavement Management Engineer |
| Manitoba Infrastructure | Al Moody | |
| New Brunswick DOT & Infrastructure | Andy Delmas | Assistant Director |
| Ministry of Transportation Ontario | Warren Lee | Pavement Design Engineer |

# APPENDIX C

## Tabulated Survey Responses

| 1. Do you consider pavement patching to be a major component of your organization's maintenance operations? | |
|---|---|
| Yes | AK, AZ, CO, CT, DE, DC, GA, HI, ID, IL, IN, IA, KS, KY, LA, ME, MD, MI, MN, MS, MO, MT, NE, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI. SC, TN, TX, UT, VT, VA, WA, WI. WY |
| No | AR, CA, FL, MA, NV |
| No Response | AL, SD, WV |

| 2. Do you have an established methodology for determining where patching is needed in your area? | |
|---|---|
| Yes | AK, CT, DE, DC, FL, GA, IL, IN, KS, ME, MD, MA, MN, MS, MO, NE, NH, NJ, NM, NY, NC, PA, SC, UT, VA, WI, WY |
| No | AL, AZ, AR, CA, CO, HI, ID, IA, KY, LA, MI, MT, NV, ND, OH, OK, OR, RI, TN, TX, VT, WA |
| No Response | SD, WV |

| 3. Is there a trigger that calls for patching? | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agency: | Visual | Size of Pothole | Depth of Rutting | Extent of Cracking | Roughness / Ravelling | Width of Joint | Scaling or Spalling | Public Complaints | Poor Ride | Safety Issue | Other |
| AL | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| AK | ● | ● | ● | ● | ● | ● | ● | | | ● | |
| AZ | ● | ● | ● | ● | ● | | ● | ● | ● | ● | |
| AR | ● | ● | | | | | | ● | | ● | |
| CA | ● | | | ● | | | | ● | | ● | |
| CO | ● | ● | | | | | | ● | ● | ● | |
| CT | ● | ● | ● | ● | | | | ● | | ● | |
| DE | ● | | ● | | ● | | ● | | | ● | |
| DC | ● | | | ● | ● | | ● | ● | ● | ● | |
| FL | ● | ● | ● | | ● | ● | ● | ● | | ● | |
| GA | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| HI | ● | | | | ● | ● | ● | ● | ● | ● | |
| ID | ● | | | | | | | | | ● | |
| IL | ● | ● | | ● | | | | ● | ● | ● | |
| IN | ● | ● | ● | ● | | | | ● | ● | ● | |
| IA | ● | ● | | | | ● | | ● | ● | ● | |
| KS | | ● | | | | | ● | ● | | ● | |
| KY | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| LA | ● | ● | | | | | | ● | ● | | |
| ME | ● | ● | ● | | | | ● | ● | | | |
| MD | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| MA | ● | | | | | | | ● | ● | ● | 1 |
| MI | ● | ● | | | ● | | | ● | ● | ● | |
| MN | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| MS | ● | ● | ● | ● | ● | | ● | | | | |
| MO | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| MT | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| NE | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| NV | ● | ● | ● | | | | | ● | | ● | 2 |
| NH | ● | ● | | | ● | ● | ● | ● | | ● | |
| NJ | ● | ● | | | | ● | | ● | | | |
| NM | ● | ● | | | | | | | | | 3 |
| NY | ● | | | | | | | ● | ● | | 4 |
| NC | ● | ● | | ● | | | ● | ● | | | |
| ND | ● | | | | | | | ● | ● | ● | |
| OH | ● | ● | | ● | | | ● | ● | | ● | |
| OK | ● | ● | ● | ● | ● | | ● | | | ● | |
| OR | | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| PA | ● | | | ● | | | | ● | | | |
| RI | ● | ● | ● | | | | | ● | ● | ● | |
| SC | ● | ● | | ● | | | | ● | ● | ● | |
| SD | | | | | | | | | | | |
| TN | ● | ● | | | | ● | | ● | | ● | |
| TX | ● | ● | | ● | | ● | | ● | | | |
| UT | ● | | ● | ● | ● | ● | ● | ● | ● | ● | 5 |
| VT | ● | ● | ● | | | | ● | ● | ● | ● | |
| VA | | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| WA | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | 6 |
| WV | | | | | | | | | | | |
| WI | ● | ● | ● | | ● | ● | | ● | ● | ● | |
| WY | ● | ● | ● | ● | ● | | ● | ● | ● | ● | |

Question 3, Other Comments

1. Traffic volumes
2. Rumble strip deterioration
3. Assigned department employees patrol the roads in their patrol area and report potholes to their patrol yard foreman.
4. Plow drivers often identify potholes during their plow routes.
5. Patching of performance-graded asphalts, stone matrix asphalt, open-graded surfaces
6. Patching is done for a variety of reasons. No single reason stands out. Triggers will vary depending on the pavement distress and individual maintenance areas.

| *4. If known, what is the average annual extent of patching repairs in your jurisdiction?* | |
|---|---|
| State | Response |
| AL | 7.50% of the total routine maintenance budget, based on actual expenditures for the last 12 mos |
| AK | 1 patch per mi, 2,000 sq. ft/mi, 25% of maintenance budget |
| AZ | 18 patches per mi, 2 syd/mi, 0.67 cyd/mi, 0.10% of maintenance budget |
| AR | 3% of maintenance budget, $4M of cost to fill potholes with about 16,000 cubic yards |
| CT | Our patching procedures are on an as need basis. Each district will set certain days to cover areas that although not hazardous have the potential to become one. |
| DE | Each district is provided $1M/year for open-ended patching (4 districts) |
| DC | 50% of maintenance budget |
| GA | 25% of road section budget (approx. $15M per year) |
| HI | 200 tons/yr |
| IL | On a typical resurfacing project 5% of the pavement area requires patching |
| IN | 1.25 tons/mile patched in 2012 |
| IA | FY 2012: $7,077,000 spent on contract patching |
| KS | 5 yr average approx. S1M or 1% of routine maintenance |
| LA | 0.72 tons per mile |
| ME | Around 20,000 tons annually |
| MD | Avg. 30,121 sq. ft and $2,622,291 emergency spot patching last 3 years |
| MN | Depends on traffic volume, age of highway, weather, size of patch needed, etc. |
| MS | 0.37 tons per lane-mile, 3.25% of maintenance budget |
| MO | 50,000 tons or $4M |
| MT | 6,2% of maintenance budget |
| NV | 5.25 cu ft/centerline mi, 0.5% of maintenance budget |
| NH | Approximately $1.5M out of total maintenance budget of $75M |
| NJ | 200,000 potholes per year |
| NM | Approximately 0.16 patches per mile, 1.5% of maintenance budget |
| NY | 80 tons demand, 23.25 tons planned per residency |
| NC | Each road section is rated a low, moderate, and severe based on percentage of surface area that is patched. |
| ND | 40% of maintenance budget in 2012 |
| OK | 125,748.34 tons statewide, 10% of maintenance budget |
| OR | 5% of maintenance budget |
| RI | Other than pothole patching and repairs to paving joints no other patching currently occurs. |
| SC | 39,581 tons of asphalt used for patching and minor leveling last year |
| TN | Our planning value seems to equate to 680# per lane-mile. 12,500 tons per year for our entire system of roughly 14,000 miles (37,000 lane-miles); 5.3% of maintenance budget |
| TX | For 2012 TXDOT repaired 495,578 potholes; expenditures totaled $9,841,506.14 |
| UT | 238,555 sy patch/mi, ave: 134.5 sy per patch 1% of maintenance budget. 1,748 patching incidents, 5,970 centerline-miles, $298,717 worth of material, large patches and lane leveling jobs skew average repair area |
| VT | 2% of maintenance budget |
| VA | 1% of maintenance budget |
| WI | Varies based on need |
| WY | 25% of road section budget (approx. $15M per year) |
| CA, CO, FL ID, KY, MA, MI, NE, OH, PA, SD, WV | No response |

5. What are the most common pavement distresses that require patching? (Click all that apply.)

| Agency: | Potholes | Rutting | Delamination | ASR, D-cracking | Raveling | Segregation | Deterioration at asphalt joint | Spalling | Concrete joint failure | Deterioration around cracks | Deterioration at previous patch | Corner Breaks | Blowups | Faulting | Punchouts | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | ● | | | | | | | ● | | | | | | | | |
| AK | ● | ● | ● | ● | ● | | | | | | | | | ● | | 1 |
| AZ | ● | ● | ● | ● | ● | | ● | ● | | ● | ● | | ● | | | |
| AR | ● | | | | ● | | | | | | | ● | | | | |
| CA | ● | ● | ● | | | | | ● | ● | | | | | | | |
| CO | ● | | ● | ● | | | ● | | ● | ● | ● | ● | | | | |
| CT | ● | ● | | ● | | | ● | | | | ● | | ● | | | |
| DE | ● | ● | | ● | | | | | ● | | ● | | ● | | | 2 |
| DC | ● | | ● | ● | | | ● | | ● | | ● | | | | | |
| FL | ● | ● | | ● | | | ● | ● | | | | | | | | |
| GA | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | ● | |
| HI | ● | | ● | | ● | | | ● | | | ● | | | | | |
| ID | ● | | | | ● | | | | | | | | ● | | | |
| IL | ● | | | ● | ● | | ● | ● | ● | ● | ● | | | | ● | |
| IN | ● | | | ● | | | ● | ● | ● | ● | ● | | | | | |
| IA | ● | | ● | ● | | | ● | ● | ● | ● | ● | | ● | | ● | |
| KS | ● | | | | | | ● | ● | | | | ● | | | | |
| KY | ● | | | | | | | | | | | | | | | |
| LA | ● | | | | | | ● | | | ● | ● | | ● | | | |
| ME | ● | ● | ● | | | | ● | | | | ● | | | | | |
| MD | ● | ● | | ● | ● | ● | ● | | | ● | | | | | | |
| MA | ● | | ● | | | | | | | | | | | | | |
| MI | ● | | | ● | | | ● | | | ● | ● | | ● | | ● | |
| MN | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | |
| MS | ● | ● | | | | | ● | | | ● | ● | | | | | |
| MO | ● | ● | ● | ● | ● | | | ● | ● | ● | ● | ● | ● | ● | | |
| MT | ● | ● | | | | | | | | ● | ● | | ● | | | |
| NE | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| NV | ● | | | | ● | | ● | | ● | ● | ● | ● | | | | |
| NH | ● | | ● | | ● | | | | | | | | | | | |
| NJ | ● | | | | | | ● | | | | | | | | | |
| NM | ● | | ● | | | | | | | | | | | | | 3 |
| NY | ● | | | | | | | | ● | | | | ● | | | |
| NC | | | ● | | | | | ● | | | | ● | ● | | | 4 |
| ND | ● | ● | | | | | ● | | | ● | ● | | ● | | | |
| OH | ● | | ● | ● | | | ● | ● | ● | | | | ● | | | |
| OK | ● | ● | | | | | ● | | | | | | | | | |
| OR | ● | ● | | | ● | ● | | | | | | | | | | |
| PA | ● | | | ● | | | | ● | | | | | | | | |
| RI | ● | | ● | | ● | | ● | | ● | | ● | | | | | 5 |
| SC | ● | | | | | | | | | | ● | | | | ● | |
| SD | | | | | | | | | | | | | | | | |
| TN | ● | | | | | | ● | | ● | ● | ● | | | | | |
| TX | ● | | | | | ● | ● | ● | ● | ● | ● | ● | | | ● | |
| UT | | ● | | | ● | | | | | ● | | ● | | | | 6 |
| VT | ● | ● | ● | | | | | ● | | ● | | | | | | |
| VA | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| WA | ● | ● | | | ● | ● | ● | ● | | ● | ● | ● | | | | 7 |
| WV | | | | | | | | | | | | | | | | |
| WI | ● | | | | | | | | ● | | | | ● | | | |
| WY | ● | ● | ● | | | | | ● | ● | | | ● | | | | |

Question 5, Other Comments

1. Permafrost induced heaving and subsidence
2. Edge cracking
3. The NM State Highway System is mostly asphalt. Only 0.3% of the NM State Highway System is PCC.
4. Alligator cracking
5. Frost heaves
6. Permafrost induced heaving and subsidence
7. Striping coincident with paint stripping

| | 6. Typically, how much time elapses between your organization becoming aware of or planning patching repairs and the completion of the patch? | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Reactive Patching | | | Planned Patching | | | | |
| Agency: | 1-7 days | 8-14 days | 15-21 days | 1-7 days | 8-14 days | 15-21 days | 22-30 days | >30 days |
| AL | | | | | | | | |
| AK | | ● | | | | | | ● |
| AZ | ● | | | | | | | ● |
| AR | ● | | | | | | | ● |
| CA | ● | | | | | | | ● |
| CO | ● | | | | | ● | | |
| CT | ● | | | ● | | | | |
| DE | | ● | | ● | | | | |
| DC | ● | | | | | | | ● |
| FL | ● | | | | | ● | | |
| GA | ● | | | | | | ● | |
| HI | ● | | | | | | | ● |
| ID | ● | | | | | | | ● |
| IL | ● | | | | | | | ● |
| IN | ● | | | | | | | ● |
| IA | | | ● | | | | | ● |
| KS | | | | | | | | |
| KY | ● | | | | | | | ● |
| LA | ● | | | | | ● | | |
| ME | ● | | | | | | | ● |
| MD | ● | | | | | | | |
| MA | ● | | | | | | | ● |
| MI | ● | | | | | | | ● |
| MN | ● | | | ● | | | | |
| MS | | ● | | | | | | ● |
| MO | ● | | | ● | | | | |
| MT | ● | | | | ● | | | |
| NE | ● | | | | | | | ● |
| NV | ● | | | | | | | ● |
| NH | ● | | | | | | ● | |
| NJ | ● | | | | | | | ● |
| NM | ● | | | ● | | | | |
| NY | ● | | | ● | | | | |
| NC | | | | | | | | |
| ND | ● | | | | | | | ● |
| OH | ● | | | | | | | ● |
| OK | ● | | | | | | | ● |
| OR | ● | | | | | | | ● |
| PA | ● | | | ● | | | | |
| RI | ● | | | | | | | ● |
| SC | ● | | | | ● | | | |
| SD | | | | | | | | |
| TN | ● | | | ● | | | | |
| TX | ● | | | | | | | ● |
| UT | ● | | | | | | | ● |
| VT | ● | | | ● | | | | |
| VA | ● | | | | | | ● | |
| WA | ● | | | | | | | ● |
| WV | | | | | | | | |
| WI | ● | | | | | | | ● |
| WY | ● | | | | | | | ● |

| Agency: | 7. Does your organization have, or work from, specifications, plans or guidelines for patching? Yes (●) Yes, but only for patching by contract (*) No (×) | | | |
|---|---|---|---|---|
| | Reactive | Planned | Temporary | Permanent |
| AL | ● | ● | ● | ● |
| AK | ● | ● | × | * |
| AZ | × | * | × | * |
| AR | ● | * | ● | × |
| CA | ● | ● | × | ● |
| CO | ● | ● | ● | ● |
| CT | × | × | × | × |
| DE | ● | ● | × | ● |
| DC | * | * | × | ● |
| FL | ● | ● | ● | ● |
| GA | ● | ● | × | ● |
| HI | × | × | × | ● |
| ID | ● | ● | ● | ● |
| IL | ● | ● | ● | ● |
| IN | ● | ● | ● | ● |
| IA | × | * | * | * |
| KS | | | | |
| KY | ● | * | ● | ● |
| LA | ● | ● | ● | ● |
| ME | ● | ● | ● | ● |
| MD | ● | * | ● | * |
| MA | × | * | ● | ● |
| MI | ● | ● | × | ● |
| MN | ● | ● | ● | ● |
| MS | × | * | × | * |
| MO | ● | ● | ● | ● |
| MT | ● | ● | | |
| NE | ● | ● | ● | ● |
| NV | × | * | × | * |
| NH | × | * | × | * |
| NJ | × | ● | × | ● |
| NM | ● | ● | ● | ● |
| NY | × | ● | ● | ● |
| NC | | | | |
| ND | × | × | × | × |
| OH | ● | ● | ● | ● |
| OK | × | × | × | × |
| OR | × | ● | × | ● |
| PA | ● | ● | ● | ● |
| RI | × | × | × | |
| SC | ● | ● | ● | ● |
| SD | | | | |
| TN | ● | ● | ● | ● |
| TX | ● | ● | × | ● |
| UT | ● | * | ● | ● |
| VT | × | × | × | × |
| VA | ● | ● | ● | ● |
| WA | × | * | × | * |
| WV | | | | |
| WI | × | * | × | ● |
| WY | ● | ● | × | ● |

| 8. What materials are used for patching asphalt pavements in your area? (Check all that apply .) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Agency: | Generic stockpile mix | Proprietary asphalt mix | Hot asphalt mix | Warm Mix Asphalt | Spray Emulsion | Polymeric Materials (e.g., epoxy) | Crumb Rubber Mastic | Other(s) (please specify) |
| AL | ● | ● | ● | | | | | |
| AK | ● | ● | ● | ● | ● | | | |
| AZ | ● | ● | | | | | | 1 |
| AR | ● | ● | ● | | | | | |
| CA | ● | | ● | | | | | |
| CO | ● | ● | ● | | | | | 2 |
| CT | ● | | ● | ● | ● | | | |
| DE | ● | | ● | ● | ● | | | |
| DC | | ● | ● | | ● | | | |
| FL | ● | ● | ● | ● | | | | |
| GA | | | ● | | ● | ● | | |
| HI | ● | | ● | | | | | |
| ID | | | ● | | ● | | | |
| IL | ● | | ● | | ● | | | |
| IN | ● | | ● | | ● | | | |
| IA | | | ● | | | | | |
| KS | ● | ● | | | ● | | | |
| KY | ● | | ● | | | | | |
| LA | ● | | ● | | | | | |
| ME | ● | ● | ● | | | | | |
| MD | | | ● | | | | | 3 |
| MA | | | ● | | | ● | | |
| MI | ● | ● | ● | | ● | ● | | |
| MN | ● | ● | ● | ● | ● | ● | ● | |
| MS | ● | ● | ● | | ● | | | |
| MO | ● | ● | ● | | ● | ● | | |
| MT | ● | ● | ● | | ● | | | |
| NE | ● | ● | ● | ● | ● | | ● | 4 |
| NV | ● | | ● | | ● | | | |
| NH | ● | | ● | | | | | |
| NJ | ● | | ● | ● | ● | | | 5 |
| NM | | | ● | | | | | 6 |
| NY | ● | ● | ● | | ● | | | |
| NC | ● | ● | ● | | ● | | | |
| ND | | | ● | | ● | | | |
| OH | | ● | ● | | ● | | | |
| OK | | | ● | | | | | |
| OR | ● | | ● | ● | | | | |
| PA | ● | | ● | ● | ● | | | |
| RI | | | ● | | | | | 7 |
| SC | ● | ● | ● | | ● | | | |
| SD | | | | | | | | |
| TN | ● | ● | ● | | | ● | | |
| TX | ● | ● | ● | | | | | |
| UT | ● | ● | ● | | | | | 8 |
| VT | ● | | ● | | | | | |
| VA | | ● | ● | | ● | | | |
| WA | ● | ● | ● | | ● | | | 9 |
| WV | | | | | | | | |
| WI | ● | ● | ● | | ● | | | |
| WY | ● | ● | ● | | ● | | | |

Question 8, Other Comments

1. Cold mix or UPM
2. Cold mix in emergency situations
3. Cold patch
4. Cold mix followed by chip seal
5. Whatever the plant is making that day. We also use low VOC patch mix (cold patch) in the winter months.
6. Hot mix is the preferred type of patching material. Cold mix patching material issued when hot asphalt is not available such as when the pothole location is too far from a hot mix plant.
7. Cold patch during winter months due to hot asphalt unavailability
8. Bagged proprietary mix
9. Chip seal patches using CRS-2P and chips

9. What materials are used for patching concrete pavement in your area? (Click all that apply.)

| Agency: | Asphalt patching material | Normal hydraulic cement mixtures (with or without accelerators) | Rapid strength hydraulic cement concrete mixtures | Other rapid setting cement mixtures (e.g., calcium aluminate, calcium sulfoaluminate, magnesium phosphate) | Gypsum-based cement mixtures | Epoxy mixtures | Latex or polymer-modified concrete | Other(s) (please specify) |
|---|---|---|---|---|---|---|---|---|
| AL | ● | ● | | | | ● | ● | |
| AK | ● | | | | | | | |
| AZ | | ● | | | | | | 1 |
| AR | ● | | ● | | | | | |
| CA | ● | | ● | ● | | ● | | |
| CO | ● | | ● | | | | | |
| CT | ● | | | ● | | | | |
| DE | ● | ● | ● | | | ● | | |
| DC | ● | ● | | ● | | | | |
| FL | ● | ● | ● | | | | | |
| GA | ● | | ● | | | ● | | |
| HI | | | ● | ● | | | ● | |
| ID | ● | | | ● | | ● | | |
| IL | ● | ● | ● | ● | | | | |
| IN | ● | ● | ● | ● | | | | |
| IA | ● | ● | ● | | | | | |
| KS | ● | | | ● | | | | |
| KY | ● | | | | | | | |
| LA | ● | ● | | | | | | |
| ME | | | | | | | | 2 |
| MD | ● | | | | | | | |
| MA | ● | | ● | | | | | |
| MI | ● | ● | ● | ● | | | | |
| MN | ● | ● | ● | | | ● | ● | |
| MS | ● | ● | | ● | | ● | | |
| MO | ● | ● | ● | | | ● | ● | |
| MT | ● | ● | | ● | | ● | | |
| NE | ● | ● | ● | | ● | ● | | |
| NV | ● | | ● | ● | | ● | ● | |
| NH | ● | | | | | | | |
| NJ | ● | ● | ● | | | | | 3 |
| NM | ● | | | | | ● | | |
| NY | ● | ● | | | | | | |
| NC | ● | ● | ● | | | | | |
| ND | | | ● | | | ● | | |
| OH | ● | ● | ● | | | | | |
| OK | ● | | ● | | | | | |
| OR | | | ● | ● | | | | |
| PA | | ● | ● | | | | | |
| RI | ● | ● | ● | | | | | |
| SC | ● | ● | ● | | | ● | | |
| SD | | | | | | | | |
| TN | ● | | | | | ● | ● | 4 |
| TX | ● | | ● | ● | | ● | ● | |
| UT | ● | | ● | ● | | ● | ● | |
| VT | | ● | | | | | | |
| VA | ● | ● | ● | | | | | |
| WA | | ● | ● | | | ● | | 5 |
| WV | | | | | | | | |
| WI | ● | ● | ● | | | ● | | |
| WY | ● | ● | ● | | | ● | ● | |

Question 9, Other Comments

1. Mr. Patch
2. We don't have concrete highways anymore, but when we did we used probably any of those.
3. Used to use latex modified but stopped due to problems experienced with longevity.
4. Large patches done on concrete with full depth patches.
5. Urefast type materials for cracking. Concrete repairs such as panel replacements are typically done by contract work.

| 10. Does your organization have any QC/QA procedures that are implemented at the time of patch placement? | |
|---|---|
| Yes | CA, FL, HI, IL, IN, IA, MD, MA, MI, MN, MO, NY, ND, PA, UT, VA |
| No | AL, AK, AZ, AR, CO, CT, DE, DC, GA, ID, KS, KY, LA, ME, MS, MT, NE, NV, NH, NJ, NM, NC, OH, OK, OR, RI, SC, TN, TX, VT, WA, WI, WY |
| No Response | SD, WV |

If yes, what properties do you measure?

- For HMA—None for concrete; polyester concrete aggregate moisture content (CA)
- Strength, bond strength, smoothness (HI)
- Permanent patches: concrete strength (IL)
- Smoothness (IN, MO)
- PCC by contract—strength HMA by contract—approved mix design (IA)
- On full-depth contract patches, density specifications are used. (MA)
- PCC—air, slump, strength (MI)
- Strength, stiffness, smoothness, and workability (MN)
- Visually inspect and inspect ride quality; also check certs on products (NY)
- Contractor patching requirements vary by the district since districts design their own plans. Most do not have density requirements but some follow same QC/QA as an asphalt overlay would. The majority follow an "ordinary compaction" method spec and pay based on meeting aggregate gradations. (ND)
- Clean patch area, vertical sides, tacking, proper amount of fill, compaction, ride quality. (PA)
- Contract patching is inspected to job specific specification. In-house small patches are unreferred. Larger patched and lane-leveling use department specs but are not tested as rigorously as contracted work. (UT)
- Density, smoothness, visual appearance (VA)

| 11. Do you use any form of automated equipment/machines for placing patches? | |
|---|---|
| Yes | AL, CT, FL, GA, IL, IN, IA, KY, MS, MI, MN, MT, NE, NJ, NY, ND, OH, PA, SC, TN, TX, VA, WA, WI, WY |
| Yes, but only for patching by contract | DE, DC, NC |
| No | AL, AR,CA,CO, HI, ID, LA, ME, MD, MA, MO, NV, NH, NM, OK, RI, UT, VT |
| No response | AZ, KS, OR, SD,WV |

| Agency: | 12. Who places patches in your jurisdiction? | | | | | | |
|---|---|---|---|---|---|---|---|
| | Reactive Patching | | | Planned Patching | | | Other(s) |
| | State forces | Paving contractor | Specialty contractor | State forces | Paving contractor | Specialty contractor | |
| AL | ● | ● | | ● | ● | | |
| AK | ● | | | ● | ● | | |
| AZ | ● | | | ● | ● | | |
| AR | ● | | | | ● | | |
| CA | ● | | | ● | ● | | |
| CO | ● | | | ● | ● | | |
| CT | ● | | | ● | | | |
| DE | ● | ● | | | ● | | |
| DC | ● | ● | | ● | ● | | |
| FL | ● | | ● | ● | ● | ● | |
| GA | ● | | | ● | ● | ● | |
| HI | ● | | | | | | |
| ID | ● | | | ● | ● | ● | |
| IL | ● | | | ● | ● | ● | |
| IN | ● | | | ● | | | |
| IA | ● | | | | | ● | |
| KS | ● | | | ● | ● | | |
| KY | ● | | | ● | ● | | |
| LA | ● | | | ● | | | |
| ME | ● | | | | ● | ● | |
| MD | ● | | | | ● | | |
| MA | ● | ● | | | ● | | |
| MI | ● | | | ● | ● | | |
| MN | ● | | ● | ● | | ● | 1 |
| MS | ● | | | ● | ● | | |
| MO | ● | ● | | ● | ● | | |
| MT | ● | | | ● | | | |
| NE | ● | | | ● | ● | ● | |
| NV | ● | | | | | ● | 2 |
| NH | ● | | | ● | ● | | |
| NJ | ● | | | ● | | | |
| NM | ● | | | ● | | | |
| NY | ● | | | ● | | | |
| NC | ● | | | ● | ● | | |
| ND | ● | | | | ● | | |
| OH | ● | ● | | | ● | | |
| OK | ● | | | ● | | | |
| OR | ● | | | ● | ● | | |
| PA | ● | | | ● | ● | | |
| RI | ● | | | | | | |
| SC | ● | | | ● | ● | | |
| SD | | | | | | | |
| TN | ● | ● | ● | ● | ● | ● | |
| TX | ● | ● | | ● | ● | | 3 |
| UT | ● | | | ● | ● | ● | |
| VT | ● | | | ● | | | |
| VA | ● | | ● | ● | | ● | 4 |
| WA | ● | | | ● | ● | | |
| WV | | | | | | | |
| WI | | | | | ● | | 5 |
| WY | ● | | | ● | ● | ● | |

Question 12, Other Comments

1. Blowpatching (MN)
2. State forces do all asphalt patching; contractors do planned concrete patching. (NV)
3. We rent spray patch injection machines, but our staff is trained to operate them. (NJ)
4. Total maintenance contracts (TX)
5. Interstate maintenance contractors (VA)
6. County Highway Departments do all maintenance for Wisconsin. (WI)

| 13. What types of traffic management procedures do you use for patching activities? (Click all that apply.) - Reactive | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Agency: | Flaggers | Lane closure with cones | Lane closure with arrow boards | Lane closure with barriers | Flashing lights and arrows on truck/equip-ment | Traffic signals | None | Other(s) |
| AL | ● | ● | ● | ● | ● | | | |
| AK | ● | ● | ● | ● | ● | | | |
| AZ | ● | ● | ● | | ● | | | |
| AR | ● | ● | ● | | ● | | | |
| CA | ● | ● | ● | | ● | | | |
| CO | ● | ● | ● | | ● | | | |
| CT | ● | ● | ● | | ● | | | |
| DE | ● | ● | ● | ● | | | | |
| DC | ● | ● | ● | | ● | | | |
| FL | ● | ● | ● | ● | ● | | | |
| GA | ● | ● | ● | | ● | | | |
| HI | | | | | ● | | | |
| ID | ● | ● | | | ● | | | |
| IL | ● | ● | ● | | ● | | | |
| IN | ● | | ● | | ● | | | |
| IA | ● | ● | ● | | ● | ● | | 1 |
| KS | ● | ● | ● | | ● | | | |
| KY | ● | ● | ● | | ● | | | |
| LA | ● | ● | | | ● | | | |
| ME | ● | | | | ● | | | 2 |
| MD | ● | | ● | | ● | | | |
| MA | | ● | ● | | ● | | | 3 |
| MI | ● | ● | ● | | | | | |
| MN | ● | ● | ● | ● | ● | | | 4 |
| MS | ● | ● | ● | | ● | | | |
| MO | ● | ● | ● | | ● | | | |
| MT | ● | ● | ● | ● | ● | | | |
| NE | ● | ● | ● | ● | ● | | | |
| NV | ● | ● | ● | | ● | | | 5 |
| NH | ● | ● | ● | | ● | | | |
| NJ | ● | ● | ● | | ● | | | 6 |
| NM | ● | ● | ● | ● | ● | | | |
| NY | ● | ● | ● | | ● | | | 7 |
| NC | ● | ● | | | | | | 8 |
| ND | ● | ● | | | ● | | | 9 |
| OH | ● | ● | ● | | ● | | | |
| OK | ● | ● | ● | ● | ● | | | |
| OR | ● | ● | ● | | ● | | | 10 |
| PA | ● | | | | ● | | | |
| RI | ● | | ● | | ● | | | 11 |
| SC | ● | | | | ● | | | |
| SD | | | | | | | | |
| TN | ● | ● | ● | | ● | | | 12 |
| TX | | ● | ● | ● | ● | ● | | |
| UT | ● | ● | ● | ● | ● | ● | | |
| VT | ● | ● | ● | | ● | | | |
| VA | ● | ● | | ● | ● | ● | | |
| WA | ● | ● | ● | | ● | | | |
| WV | | | | | | | | |
| WI | ● | ● | ● | | ● | | | |
| WY | ● | ● | ● | ● | ● | | | |

Question 13, Other Comments

1. All patching activities follow department standards for traffic control. (IA)
2. Work zone signing (ME)
3. Police detail (MA)
4. Changeable message boards (CMB) and dynamic message signs (DMS) (MN)
5. Lane closure with barriers for planned concrete patching only (NV)
6. Police slow-downs for reactive patrols (NJ)
7. Automated assisted flagging devices (NY)
8. Extent of traffic control depends on traffic volumes (NC)
9. Pilot car used when needed (ND)
10. Tough question as it depends on repair type and type of road etc. (OR)
11. Moving operations as well (RI)
12. Answers above depend on what roadway type. (TN)

| Agency: | 14. Do you monitor the performance of installed patches? | | | | | |
|---|---|---|---|---|---|---|
| | Reactive | | | Planned | | |
| | Yes | Yes, but only for patching by contract | No | Yes | Yes, but only for patching by contract | No |
| AL | | ● | | | ● | |
| AK | ● | | | ● | | |
| AZ | ● | | | ● | | |
| AR | ● | | | ● | | |
| CA | | | ● | | | ● |
| CO | ● | | | ● | | |
| CT | ● | | | ● | | |
| DE | | | ● | | ● | |
| DC | | ● | | | ● | |
| FL | ● | | | ● | | |
| GA | ● | | | ● | | |
| HI | | | ● | | | ● |
| ID | | | ● | ● | | |
| IL | | | ● | ● | | |
| IN | ● | | | ● | | |
| IA | | | ● | | | ● |
| KS | | | ● | | | ● |
| KY | ● | | | ● | | |
| LA | | | ● | | | ● |
| ME | | | ● | ● | | |
| MD | ● | | | ● | | |
| MA | | | ● | | | ● |
| MI | ● | | | ● | | |
| MN | ● | | | ● | | |
| MS | ● | | | ● | | |
| MO | | ● | | | ● | |
| MT | ● | | | ● | | |
| NE | ● | | | ● | | |
| NV | | | ● | | | ● |
| NH | | | ● | | | ● |
| NJ | | | ● | | | ● |
| NM | | | ● | | | ● |
| NY | ● | | | ● | | |
| NC | | | ● | ● | ● | |
| ND | | | ● | | | ● |
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| OK | ● | | | ● | | |
| OR | | | ● | | | ● |
| PA | | | ● | ● | | |
| RI | | | ● | | | |
| SC | | | ● | | | ● |
| SD | | | | | | |
| TN | | | ● | | | ● |
| TX | | | ● | | | ● |
| UT | ● | | | ● | | |
| VT | | | ● | | | ● |
| VA | | | ● | ● | | |
| WA | | | | | ● | |
| WV | | | | | | |
| WI | | | ● | | | ● |
| WY | | | ● | | | ● |

| 15. Do you have an established methodology to track the location of patches that have been placed in your area? | | | | |
|---|---|---|---|---|
| | Reactive | | Planned | |
| Agency: | Yes | No | Yes | No |
| AL | | ● | | ● |
| AK | ● | | ● | |
| AZ | | ● | | ● |
| AR | | ● | ● | |
| CA | | ● | | ● |
| CO | ● | | ● | |
| CT | ● | | ● | |
| DE | ● | | ● | |
| DC | ● | | ● | |
| FL | ● | | ● | |
| GA | ● | | ● | |
| HI | | ● | | ● |
| ID | | ● | | ● |
| IL | | ● | | ● |
| IN | ● | | ● | |
| IA | | ● | | ● |
| KS | | ● | | ● |
| KY | | ● | | ● |
| LA | ● | | ● | |
| ME | ● | | ● | |
| MD | ● | | ● | |
| MA | | ● | | ● |
| MI | ● | | ● | |
| MN | | | ● | |
| MS | ● | | ● | |
| MO | ● | | ● | |
| MT | | ● | ● | |
| NE | | ● | | ● |
| NV | | ● | | ● |
| NH | | ● | | ● |
| NJ | | ● | | ● |
| NM | | ● | | ● |
| NY | | ● | ● | |
| NC | | ● | | ● |
| ND | | ● | | ● |
| OH | ● | | ● | |
| OK | | ● | | ● |
| OR | | ● | | ● |
| PA | | ● | ● | |
| RI | | ● | | |
| SC | ● | | ● | |
| SD | | | | |
| TN | ● | | ● | |
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| UT | | ● | ● | |
| VT | ● | | ● | |
| VA | | ● | ● | |
| WA | ● | ● | ● | ● |
| WV | | | | |
| WI | | ● | | ● |
| WY | | ● | | ● |

<table>
<tr><th>State</th><th colspan="4">16. What is the average unit cost of patches in your area?</th></tr>
<tr><td>Alabama</td><td colspan="4">The average cost is approximately $1,000 per ton.</td></tr>
<tr><td>Alaska</td><td colspan="4">Asphalt patching $1.30/sq. ft; crack sealing $2.00/lft; emulsion/chip $1.35/sq. ft. All above include striping.</td></tr>
<tr><td>Arizona</td><td colspan="4">Not readily available and difficult to estimate. In FY 2012, we expended about $4M of the $130M maintenance budget to fill potholes with about 16,000 cubic yard of material.</td></tr>
<tr><td>Arkansas</td><td colspan="4">$473.00 per cubic yard for temporary maintenance costs</td></tr>
<tr><td>California</td><td colspan="4">Don’t track</td></tr>
<tr><td>Connecticut</td><td colspan="4">Cost per ton</td></tr>
<tr><td>Delaware</td><td colspan="4">~$110/ton for cold patch (temporary material) ~ $80/ton for mainline patching</td></tr>
<tr><td>District of Columbia</td><td colspan="4">$250 per ton hand-laid asphalt patch in-place under contract; $300 per ton hand-laid asphalt in-place; DC forces—Work includes remove and replace</td></tr>
<tr><td>Florida</td><td colspan="4">Estimated engineering cost per ton is $293.21 for manual patching and $166.79 per ton for mechanical patching.</td></tr>
<tr><td>Hawaii</td><td colspan="4">$200/ton</td></tr>
<tr><td>Idaho</td><td colspan="4">Our Maintenance Management System was just implemented and costs are not available.</td></tr>
<tr><td>Illinois</td><td colspan="4">Hot mix asphalt: $120/sq. yd; jointed PCC: $150/sq. yd; continuously reinforced PCC: $170/sq. yd.</td></tr>
<tr><td>Indiana</td><td colspan="4">Shallow patches: $450.87 for fiscal year 2012—Unit cost, which is total cost per ton of accomplishment. Deep patching: $259.35 for fiscal year 2012—Unit cost, which is total cost per ton of accomplishment.</td></tr>
<tr><td>Iowa</td><td colspan="4">Data are very variable depending on type of patch, quantity, location, and other factors.</td></tr>
<tr><td>Kansas</td><td colspan="4">Approx. $400 per ton (frontline cost only)</td></tr>
<tr><td>Kentucky</td><td colspan="4">State forces $60 per ton; contract forces $85 per ton</td></tr>
<tr><td>Louisiana</td><td colspan="4">$307 per ton; this includes material, labor, equipment, and overhead.</td></tr>
<tr><td>Maine</td><td colspan="4">$350 per ton (including all labor, materials, and equipment)</td></tr>
<tr><td>Massachusetts</td><td colspan="4">HMA patching = $150–$200/ton; traffic control = $1,000/night; police (if required) = $400/night</td></tr>
<tr><td>Mississippi</td><td colspan="4">The average cost per placed ton for “spot patching” for FY 2012 was about $423 state-wide for hot or cold mix asphalt placed manually. The average cost for larger patches placed with a paver was about $110 per ton in-place.</td></tr>
<tr><td>Michigan</td><td colspan="4">$120–150/ton HMA $90–95/sq. yd PCC</td></tr>
<tr><td>Minnesota</td><td colspan="4">Average price of asphalt hot mix is $75 per ton (depends on plant and material)</td></tr>
<tr><td>Missouri</td><td colspan="4">$80 per ton</td></tr>
<tr><td>Montana</td><td colspan="4">Hand patching $4.57/sq. ft; machine patching $4.63/sq. yd; rut fill $2.00 linear foot</td></tr>
<tr><td>Nevada</td><td colspan="4">$45.00/cu. ft</td></tr>
<tr><td>New Hampshire</td><td colspan="4">N/A—Just beginning to track these numbers</td></tr>
<tr><td>New Jersey</td><td colspan="4">$354 per ton for manual pothole repair; less for spray patch injection technology, more for permanent patching.</td></tr>
<tr><td>New Mexico</td><td colspan="4">In 2012, NMDOT spent $281,929 on pothole patching and $204,775 on emergency hand patching. NMDOT does not have any automated patching equipment. All patching is done with state forces.</td></tr>
<tr><td>North Carolina</td><td colspan="4">When part of a TIP project, value is $195/yd$^2$</td></tr>
<tr><td>North Dakota</td><td colspan="4">Estimated cost/mile for 2 in. contract patching is $150,000/mile (It seems like these types of projects often end up more like an overlay than patching a few intermittent bad areas.)</td></tr>
<tr><td>Ohio</td><td colspan="4">Rigid removal and rigid replacement with drilled-in dowels and tie bars ~$100/sq. yd. Flexible partial depth ~$150/cu. yd</td></tr>
<tr><td>Oklahoma</td><td colspan="4">$103.68/ton in 2012</td></tr>
<tr><td rowspan="5">Pennsylvania</td><td>Assembly/Activity</td><td>Costs</td><td>Production</td><td>Per Prod Unit</td></tr>
<tr><td>711712101<br>Roads—Paved<br>Patch Manual</td><td>$10,252,721.88</td><td>21,269.686/ton</td><td>$482.03</td></tr>
<tr><td>711712102<br>Roads—Paved<br>Patch-Manual<br>Emerg.</td><td>$1,502,882.24</td><td>2,295.180/ton</td><td>$654.80</td></tr>
<tr><td>711712103<br>Roads—Paved<br>Patch—<br>Man Pipe Trench</td><td>$3,215,907.38</td><td>12,946.999/ton</td><td>$248.39</td></tr>
<tr><td>Total</td><td>Total<br>$14,971,511.50</td><td>36,511.865/ton</td><td>$410.05</td></tr>
<tr><td>South Carolina</td><td colspan="4">The cost for routine patching with in-house forces for fiscal year 2011/2012 was $325 per ton of material used. This includes our loaded labor rate, equipment rental rate, and the cost of materials. This includes both patching by injection machine and by hand.</td></tr>
</table>

| State | 16. What is the average unit cost of patches in your area? |
| --- | --- |
| Tennessee | Our budget cost for Activity 401 Manual Spot Patching is $515 per ton; however, our reported cost per ton is $312.76. |
| Utah | All costs are for state forces only. Patch size distribution 826 0–9 SY; 814 10–99 SY; 90 100–999 SY, 18 >1000 SY. Average cost: $9.04 per SY; Patches < 10 SY ea average $240 per SY; Patches < 5 SY ea average $349.50 per SY; Statewide total $2,156,784 for labor, equipment, and materials. 1,784 separate patching jobs 238,555 SY patched |
| Vermont | $179.00 per ton in place (average) |
| Virginia | Cost per patch is difficult to determine because of work scopes and traffic control set ups required. Varies considerably. |
| Washington | Varies by region and maintenance area. Costs are not well documented but we are working to do so. |
| Wyoming | Contract prices: Asphalt patching $75/ton; Concrete slab replacement $117/sq. yd; Concrete pavement spall repair $91/sq. ft; In-house maintenance prices: Hand patching (pothole repair) $425/ton; motor grader patching $105/ton; motor grader leveling $85/ton; Laydown machine leveling $90/ton; spray injection patching $410/ton; Concrete paving repair $52/sq. ft. |

| Agency: | 17. Has your organization undertaken or sponsored research in the area of patching? | | | If yes to the question above, what are the main areas of research? | | | | |
|---|---|---|---|---|---|---|---|---|
| | Yes | No | Planning to initiate research. | Performance | Triggers | Management | Speed of repairs | Cost effectiveness |
| AL | | ● | | | | | | |
| AK | ● | | | ● | ● | ● | | ● |
| AZ | | ● | | | | | | |
| AR | | ● | | | | | | |
| CA | | ● | | | | | | |
| CO | | ● | | | | | | |
| CT | ● | | | ● | | | ● | |
| DE | | ● | | | | | | |
| DC | | ● | ● | | | | | |
| FL | | | ● | ● | ● | ● | ● | ● |
| GA | | ● | | | | | | |
| HI | | ● | | | | | | |
| ID | | ● | | | | | | |
| IL | ● | | | ● | | | | |
| IN | ● | | | | | | | |
| IA | | ● | | | | | | |
| KS | | ● | | | | | | |
| KY | | ● | | | | | | |
| LA | | ● | | | | | | |
| ME | ● | | | ● | | | ● | ● |
| MD | | ● | | | | | | |
| MA | | ● | | | | | | |
| MI | ● | | | | | | ● | |
| MN | ● | | | ● | ● | ● | | ● |
| MS | ● | | | ● | ● | | | |
| MO | ● | | | ● | | | | |
| MT | | ● | | | | | | |
| NE | | ● | ● | ● | | | | ● |
| NV | | ● | | | | | | |
| NH | | ● | | | | | | |
| NJ | | ● | | | | | | |
| NM | | ● | | | | | | |
| NY | ● | | | ● | | | | ● |
| NC | | ● | | | | | | |
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| OH | | ● | | | | | | |
| OK | | ● | | | | | | |
| OR | | ● | | | | | | |
| PA | | ● | | | | | | |
| RI | | ● | | | | | | |
| SC | | ● | | | | | | |
| SD | | | | | | | | |
| TN | ● | | | ● | | | | ● |
| TX | ● | | | ● | | | | |
| UT | ● | | | ● | | | ● | ● |
| VT | | ● | | | | | | |
| VA | | ● | | | | | | |
| WA | ● | | | | | ● | | ● |
| WV | | | | | | | | |
| WI | | ● | | | | | | |
| WY | | ● | | | | | | |

18. Is there a need for more research or information on (click all that apply):

| Agency: | Comparison of different materials? | Comparison of different patching procedures? | Development of new or innovative patching materials? | Development of new or improved patching procedures? | Development of new or improved equipment? | Understanding of causes of distresses needing patching? | Understanding performance of different patching materials? | Improved maintenance (patching) management? | The way records are kept and what they contain? | Improved guidance, training and specifications? | Improved patching standards? | Use of bonding agents? | Coordination of road repairs where possible? | Use of trenchless technologies? | Other(s) (please specify) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | | | | | | | | | | | | | | | |
| AK | ● | ● | ● | ● | ● | ● | ● | ● | | | | | | | |
| AZ | | | | | ● | ● | | | | ● | | ● | | | ● |
| AR | | | ● | ● | | | | | | | | | | | |
| CA | ● | | | ● | | ● | ● | | ● | ● | ● | | | | |
| CO | ● | ● | ● | ● | ● | | ● | ● | | ● | ● | ● | ● | ● | |
| CT | ● | | ● | ● | ● | | ● | | | | | | ● | ● | |
| DE | ● | ● | ● | ● | ● | | ● | | | | | | | | |
| DC | ● | ● | ● | ● | | | | ● | ● | | | ● | | ● | |
| FL | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| GA | | | | | | | | | | | | | | | |
| HI | | ● | ● | | | ● | ● | | | | | | | | |
| ID | | | | | ● | | | | ● | | | | | | |
| IL | ● | ● | | | | | ● | | | | | | | | |
| IN | | ● | ● | | | | ● | | | ● | ● | | | | |
| IA | ● | ● | | ● | ● | | | ● | ● | | | ● | | | |
| KS | ● | ● | ● | ● | | | | | | ● | | | | | |
| KY | | | ● | ● | | | | ● | ● | | | | | | |
| LA | ● | ● | ● | | | | ● | ● | | | | | | | |
| ME | ● | ● | ● | | | | ● | | | | | ● | | | |
| MD | ● | | ● | ● | ● | | | | ● | | | ● | | | |
| MA | ● | | | | | | | | | | ● | | | | |
| MI | | | ● | ● | | | | | | | | | | | |
| MN | ● | ● | ● | ● | ● | ● | ● | | | ● | ● | ● | ● | ● | ● |
| MS | ● | ● | | | ● | | | ● | | ● | | | | | |
| MO | | | | | | ● | ● | | | | | ● | | | |
| MT | ● | | ● | ● | ● | | | | | | | ● | ● | ● | |
| NE | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● | ● | |
| NV | ● | | | | ● | | ● | ● | ● | ● | ● | ● | | | |
| NH | ● | ● | ● | | | | | | | | ● | ● | ● | | |
| NJ | | | | | | | | | | | | | | | |
| NM | ● | ● | | | ● | | ● | | | ● | | | | | |
| NY | ● | | ● | | | | | | | | | | | | |
| NC | ● | ● | ● | ● | ● | | ● | | ● | ● | | ● | | | ● |
| ND | ● | ● | ● | | | | ● | ● | | | | | | | |
| OH | | | | | | | | | | | | | | | |
| OK | | | | | | | | | | | | | | | ● |
| OR | | | | | | | | | | | | | | | |
| PA | | | | ● | | | | | | | | | | | |
| RI | | ● | | ● | | | | ● | ● | ● | ● | | ● | ● | ● |
| SC | | | ● | | | | | | | | | | ● | ● | |
| SD | | | | | | | | | | | | | | | |
| TN | | | | | | | | | | | | | | | |
| TX | | | | ● | ● | | | ● | | | | | | | |
| UT | ● | ● | ● | ● | ● | ● | ● | ● | | | | ● | | ● | |
| VT | ● | | | | | | | | | | ● | | | | |
| VA | ● | ● | ● | ● | ● | | ● | | | | ● | | | | |
| WA | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | |
| WV | | | | | | | | | | | | | | | |
| WI | ● | ● | ● | ● | | | ● | ● | | | | ● | | ● | |
| WY | | | | | | | | ● | ● | ● | | | | | |

Abbreviations used without definitions in TRB publications:

| | |
|---|---|
| A4A | Airlines for America |
| AAAE | American Association of Airport Executives |
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ACI–NA | Airports Council International–North America |
| ACRP | Airport Cooperative Research Program |
| ADA | Americans with Disabilities Act |
| APTA | American Public Transportation Association |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ATA | American Trucking Associations |
| CTAA | Community Transportation Association of America |
| CTBSSP | Commercial Truck and Bus Safety Synthesis Program |
| DHS | Department of Homeland Security |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FHWA | Federal Highway Administration |
| FMCSA | Federal Motor Carrier Safety Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| HMCRP | Hazardous Materials Cooperative Research Program |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISTEA | Intermodal Surface Transportation Efficiency Act of 1991 |
| ITE | Institute of Transportation Engineers |
| MAP-21 | Moving Ahead for Progress in the 21st Century Act (2012) |
| NASA | National Aeronautics and Space Administration |
| NASAO | National Association of State Aviation Officials |
| NCFRP | National Cooperative Freight Research Program |
| NCHRP | National Cooperative Highway Research Program |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| RITA | Research and Innovative Technology Administration |
| SAE | Society of Automotive Engineers |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005) |
| TCRP | Transit Cooperative Research Program |
| TEA-21 | Transportation Equity Act for the 21st Century (1998) |
| TRB | Transportation Research Board |
| TSA | Transportation Security Administration |
| U.S.DOT | United States Department of Transportation |